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LEVERAGE TECHNOLOGY FOR 21st CENTURY METASYSTEMS

Accord Solutions, Inc.

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13. ABSTRACT (Maximum 200 words)

The objective of this effort was to identify technology leverage opportunities for advancing information technology that can meet the next century's battlespace challenge. Special attention was paid to capabilities for building metasystems which can incorporate intelligence into systems and provide common understanding and simulation to support organization and doctrine change. Special critical barriers hindering improvement were identified: closing the gap between demonstations and fielded systems, re-engineering warfare, creating and integrating the metasystem, and meaningful communication and common understanding. To overcome these barriers, an Intelligent Exchange interface was proposed, a set of associated technical capabilities that will empower users and operators to improve large scale command and control systems. These capabilities included Safe Synthesis (a means of enabling flexible personal control by the user) Confidence Constraints and Models (a way to constraint user's choices to conform to coordinated activity), Consistent Interaction (a mechanism to provide consistent viewpoints of reality) and Personal Viewpoint and Mastery (a way to express, observe and use one's personal mastery in a way to make the system more effective). An example experiment for incorporating these capabilities was described built around "The Warrior's Personal Decision System".

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1. Overview and Summary

1.1 The Battlespace Challenge

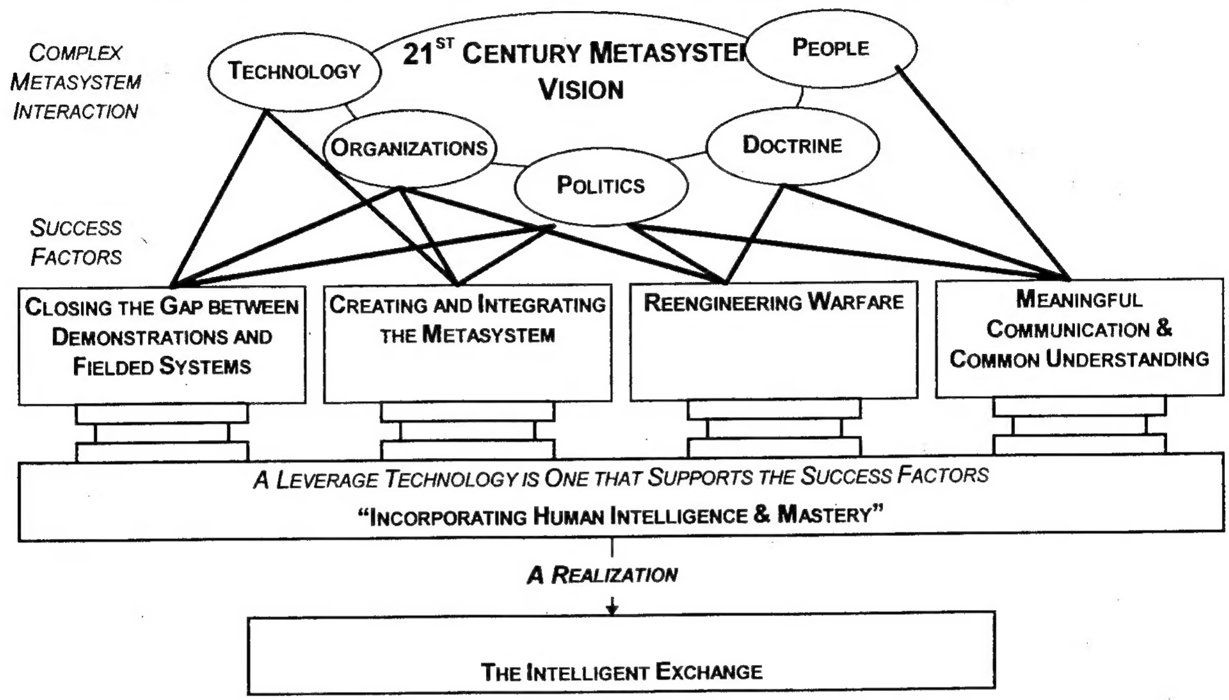
In the 21st Century, military battles will be decided largely by the quality of systems to support information flow and decision making [Cyber]. Visions of such systems typically stress two attributes. First, myriad components and technologies will be joined into a system-of-systems, or metasystem. This is a difficult technical area because a high degree of complexity results from numerous intersystem connections. Second, the metasystem's success will depend heavily on how easily and effectively humans can interact with and through it. The metasystem includes significant interaction with humans and related structures. Some examples are: military organization structure, military doctrine, personnel training infrastructure, prior legacy systems, generation of plausible scenarios, and other human related topics. This compounds the technical interaction complexity significantly. Therefore, we add a third attribute, that the success of the metasystem depends upon empowering humans to make it work. We conclude that the 21st Century Metasystem depends upon giving users the capability to personally control and apply their individual mastery over and above knowledge sources supplied by others. As a result, they can use the system in a way that lets them help make the system work.

Figure 1-1 – Report Overview – Relating Visions to Leverage Technology – sketches the 21st Century Metasystem complexity. The first level shows complexity arising due to numerous technical and non-technical interactions. The second level in the figure shows some success factors – ie, external conditions necessary to reach the 21st Century Metasystem Vision. The third level of Figure 1-1 shows the selected leverage technology, one that strongly supports all the success factors. This is "Incorporating Human Intelligence & Mastery." The figure suggests that the leverage technology supports each of the success factors.

1.2 The Leverage Technology

The selected leverage technology, Incorporating Human Intelligence & Mastery, must make the 21st Century Metasystem vision easier to achieve and be more effective for its users. The realization of this selection is an intelligent user-metasystem interface that the user personally tunes, enhancing standard system capabilities to meet her own knowledge and decision making needs. Using it, the user is made capable of synthesizing applications from components. While quite flexible, the interface constrains the user to conform to authority, applicable military doctrine, mission plans and metasystem operations. The interface also ensures that the personal system and knowledge shared by others is used consistently. In addition, the user can change presentation manner and representation focus to reflect their personal conceptual bandwidth for the application at hand. To avoid confusion with other ideas that combine the concepts of cognition and systems, this interface will be called an *Intelligent Exchange*, or *IE*. This realization and its layers are shown in Figure 1-2 – Elements of the Intelligent Exchange.

Figure 1-1—Report Overview—Relating Visions to Leverage Technology



1.3 A Realization—The Intelligent Exchange

This report defines the Intelligent Exchange and suggested a set of associated technical capabilities that are needed to make it work effectively. The Intelligent Exchange directly supports incorporating human intelligence and mastery into systems. To accomplish this Intelligent Exchange puts humans in control of their personal decision system. Through personal control it maximizes human effectiveness, letting users teach and control their metasystem entry point to best represent their personal mastery over their military role and the particular situation. Second, it provides an interactive consistency between users that makes it easier to communicate through the metasystem. Third, users are constrained to work within the bounds that prevent them from interfering with the needs of higher level authority. The combination allows humans to help make their 21st Century Metasystems work. Therefore, the Intelligent Exchange emphasizes human effectiveness. This emphasis is consistent with the Air Force's long range vision document, "New World Vistas," that states that:

> *"All Air Force systems must be human-centered, from design to operations. People are central to all Air Force activities. No matter how the battlefield of a particular future conflict evolves, and no matter what mix of power is used, there will always be a human in every loop, to exercise command and control. [Vistas]*

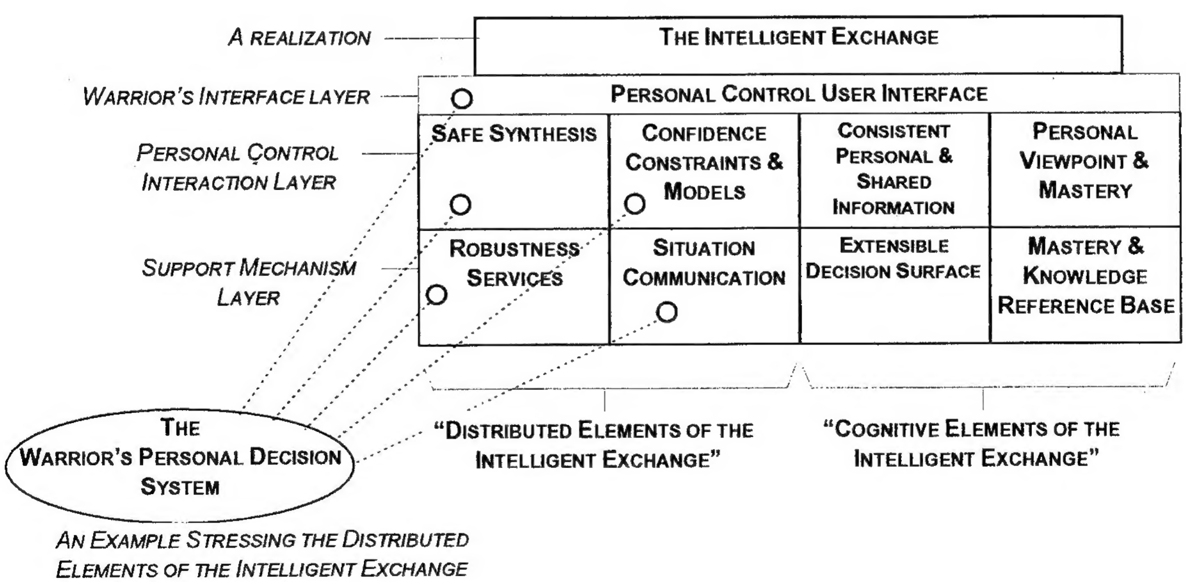
1.4 Approach

Our approach, following Figure 1-1—Report Overview—Relating Visions to Leverage Technology, is to identify success factors, ie—important human, organizational, technical and political capabilities that are necessary for the 21st Century Metasystem to reach a high effectiveness level. A leverage technology would necessarily lead to solutions to several of these success factors. Thus, our analysis seeks a common element among system building and scaling technology and among the organizational and infrastructure interfaces necessary to make many parts of the success factors come to fruition.

The Intelligent Exchange is shown in Figure 1-1 as one realization of the leverage technology. This report uses the Intelligent Exchange to better define the meaning of incorporating human intelligence and mastery as is necessary to support the success factors and accomplish visions of 21st Century System goals.

Figure 1-2—Elements of the Intelligent Exchange—names the elements of the Intelligent Exchange and shows its two layers. An example of the Intelligent Exchange, the Warrior's Personal Decision System(WPDS), is used to put the Intelligent Exchange in context. It stresses the Safe Synthesis, Confidence Constraints & Models, Robustness Services and Situation Communications elements of the technology. Building a WPDS would be a first step in creating a primitive Intelligent Exchange.

Figure 1-2—Elements of the Intelligent Exchange



1.5 *Large Scale Metasystem Success Factors*

Large scale command and control systems exist in order to give each user a timely, broader and deeper perspective of the battle situation and to communicate plans, commands and intelligence information. The improved battlespace perspective allows each level of command to react and decide faster and more accurately to threats and opportunities. The successful 21st Century Metasystem would allow for a more closely coordinated action where information and commands are more thoroughly analyzed on a more rapid time scale. The holders of this technology can control the tempo of the battlespace. The command structure would be able to be more responsive and react faster. Progress toward this goal must be the central point of new system technology.

Success factors are enabling conditions that result from both operational environment and the methods of use of technology by humans. The four given here are not necessarily complete, but represent a critical set believed to be crucial to the accomplishment of effective 21st Century Metasystems. They are:

- Closing the Gap between Demonstrations and Fielded Systems
- Reengineering Warfare
- Creating and Integrating the Metasystem
- Meaningful Communication & Common Understanding

1.6 Incorporating Human Mastery & Intelligence into the Metasystem

A leverage technology would provide a contribution to elements of each of these success factors. Incorporating Human Mastery & Intelligence is the selected leverage technology because it provides critical needs in each of the success factors. Our description of an approach to this is the Intelligent Exchange(IE). It is a personal control veneer added to the metasystem to empower users and operators to improve the system to meet their needs.

The 21st Century Metasystem success factors depend strongly upon human involvement in myriad ways. The Intelligent Exchange is a means of "Incorporating Human Mastery & Intelligence" into the Metasystem. In this concept the ultimate judge of the system effectiveness is the user himself. Therefore, the incorporation of human intelligence into systems places the final stage of organization and optimization of the system in the hands of the humans who are involved in it on a day-to-day basis. In these future systems, the individual will depend upon advanced information technology, built by conventional means—eg, reusable components, intelligent data mining, inference engines, adaptive search agents, automated associates, and large scale knowledge bases. These core functions will be characterized by their content of an "expert" body of knowledge and experience that is captured by analysis, design and coding by programmers. While such knowledge bases provide a valuable reference, they only give a surface understanding compared to the depth of experience that each military professional can bring to bare on a problem. The leverage technology must give these Warriors the capability to capture their extra layers of knowledge and experience that can only come from being in the place, situation and history of an individual professional. We stress that mastery captured by

the involved user, who understands how to carry out the action and its consequences, is the key to the success of personal control.

> *"The mastery over reality, both technical and social, grows side-by-side with the knowledge of how to use words. ... The right word for an action, for a trick of the trade, for an ability, **acquires meaning in the measure in which the individual becomes capable to carry out this action.**" [Malinowski]*

Therefore, an individual's mastery comes from the knowledge gained through personal control, studied reaction and acquired depth of knowledge. This gives the individual power over the artificial reality created by information tools, knowledge bases and a diversity of data sources. In this framework, the intelligence incorporated into the metasystem by the user is a personal supplement to the background knowledge, associate processes, information and data decision and planning functions normally associated with computer systems. The Intelligent Exchange is a means of addition of a personal mastery veneer into the system (The Personal Control User Interface). In addition, it requires the interaction layer with the following:

- A means of enabling a highly flexible personal control by the user to assemble components (Safe Synthesis)
- Constraints on the user's choices to conform to coordinated activity (Confidence Constraints & Models)
- A mechanism to provide consistent viewpoints of reality among participants (Consistent Interaction)
- A way to express, observe and use one's personal mastery in a way makes the system effective for the user (Personal Viewpoint & Mastery)

Operations not directly accessible by the user are necessary. These are embodied in the Support Mechanism Layer. (See Figure 1-2—Elements of the Intelligent Exchange). Two of these are distributed across the metasystem: Robustness Services and Situation Communication. Two of them are local and require research into cognitive, decision and knowledge representation methods: Extensible Decision Surface and Mastery & Knowledge Reference Base.

1.7 Relationship of the Intelligent Exchange to Advanced Knowledge Based Systems

Knowledge based systems(KBS) provide a superior problem solving environment compared to conventional programming. They are capable of answering unanticipated questions and interpreting unforeseen events. New knowledge can be added to its rules, relationships and fact base. KBS browsers and composition methods of connecting multiple KBS domains are active research areas. KBS inference engines add a significant degree of flexibility to the user's questions and information gathering. They are expected to contribute significantly to the metasystem and its success. However, KBSs are inherently monoliths, and are maintained and improved by a central staff of computer skilled people and a few domain experts. Its

fundamental assumption is that domain experts transfer all the knowledge needed and that users will see things in the same manner as the expert.

The Intelligent Exchange is the next step in applying human knowledge and skills. Like the KBS, It would rely on a number of automated associates and knowledge bases as information and decision resources. However, it differs from integrated knowledge bases in that the Intelligent Exchange gives a personality veneer on top, coupled with system controls to give flexible personal control over detection, observation, processing and reaction. Its underlying assumption is those professional users, who are highly involved and active, have a veneer of expertise above and beyond that placed in a common knowledge base. In fact, that personality veneer contains a significant amount of context and tacit knowledge that cannot be expressed completely by the domain expert to the computer scientist. This last veneer, or "mastery" can only be added by the user. As participants in the field, users observe, recognize solutions and create powerful means and reactions that might not occur to the out-of-context expert. Thus, the Intelligent Exchange would be a means of building upon the centrally developed expertise. The Intelligent Exchange allows users to incorporate widely diverse environments and situations into creative solutions far beyond what a centralized KBS could contain.

Since the highly competent professional user cannot be expected to learn the intricate details of knowledge representation or programming, the Intelligent Exchange gives him personal control and access to a wide range of system resources. The user would identify and control the combination of events and knowledge into a reactive knowledge base to perform the human's creative functions. Objects contained in the Intelligent Exchange are created by the user's interaction with local and distributed computer and communication resources. With the Intelligent Exchange each user could combine multiple event notices and displays into a meaningful object for the mission at hand. Suppose a new threat is recognized by the user through the combination of information gathered about its visual and infrared images, electromagnetic jamming, radar profile and defensive maneuvers. To save a recognition case, the user would identify the combination of events and observations to the Intelligent Exchange. This would "teach" the Intelligent Exchange to trigger when a similar combination occurs. This event creation would entail blocking out uninteresting areas of screens and highlighting interesting ones. Also it would allow for the following:

- Selection of table lookup data
- Synthesis of signal processing
- Direction of object and relational data base access
- Direction of knowledge base access
- Visualization of combined data elements
- Generation of new expert rules

For example, the user could link together image analysis and detection tools to define or confirm a new event.

The Intelligent Exchange, with the human's guidance, is proactive—control is extended into the computational environment to include capturing of sensor signals, screen images, table

values, processing, correlation, recognition, and reaction. By building upon a template knowledge base, the user could extend it for their personal use. By making the system effective for their personal operations (and with the confidence from consistency verification) the user makes a significant contribution to the success of the metasystem.

1.8 Report Overview

Chapter 2 describes success factors for 21st Century Metasystems. Chapter 3 uses the "Warriors Personal Decision System" to establish the needs of Warrior information systems. Chapter 4 gives an overview of the Intelligent Exchange as the technology for incorporating human intelligence and mastery into the metasystem. Chapter 5 describes a layered architecture of components. Included are the background goals for each component as well as the supporting technology for its operation and environment. Chapter 6 summarizes the value and benefits of the key personal control components of the intelligent exchange.

Appendix A – General Technology Needs in Warrior Centric Systems – provides a description of the Global Access and General Programming models that are required to provide a foundation for the Intelligent Exchange.

2. The 21st Century Metasystem Success Factors

2.1 Defining Success Factors

This is a discussion of human, organization, political and technical factors that may cause difficulties in building an effective metasystem. Included are elements that may are may not be supported by the leverage technology. Our goal is to establish that many of the elements of these success factors are resolved by the leverage technology.

2.2 Closing the Gap between Demonstrations and Fielded Systems

There is a gap between what can be done in a controlled environment and what can be delivered and put into military practice. Technology can often deliver examples of ideas in the small-system context, however, it is often difficult to deliver on promises derived from the example. For example, in a recent telemedicine demonstration, Walter Reed Hospital performed an agile medicine demonstration with shipboard medics through a collaboration system. The necessary communications and computational systems were shown to be feasible. However, the point-to-point arrangement does not reflect the infrastructure or design needed for making this an operational reality. In addition, medic training is generally lacking about how to deal with the medical issues and set up the point-to-point communication networks effectively. (Specially trained system technicians and medical staff were airlifted to the ship to accomplish the demonstration.) Some examples of scaling difficulties are: scaling, matching skills, collaborative team building and cognitive overload.

2.2.1 Scaling

The most difficult technology scaling challenge is one that can ensure that the operational framework fits the C4I operating context, with wide ranging, dynamic resource demands yet with constant operation over a twenty-four hour, seven day basis. This means that system controls must be capable of measuring and understanding the capability of the system and determining an anticipated time response, including any delays due to operational robustness measures. A high degree of generality (portability and operability) of new applications is necessary because a solution must ensure that today's software—where most of the investment is—is not compromised when computational and communication capacities change with hardware and system upgrades. Simple point-to-point solutions to demonstrate capability typically omit full system robustness and recovery measures. Often the gap is hidden because of demonstration "in the small." For example, in a communications system, a quick recovery from switching station loss requires a more complex design than a simple point-to-point one with no robustness features. It also may also be planned to operate only for the short period necessary for a demonstration. The large-scale systems become complex because context and interactions may grow exponentially to achieve full scale military robustness. They must also operate over several lifetimes of their physical components.

2.2.2 Matching Skills

Another technology gap occurs because systems are often too complicated and difficult to set up in the field. Many system demonstration efforts lose sight of the skill level required for users, support and installers. Operation at the Joint Chiefs level is often feasible due to the extra level of expertise applied to the function. When fielded for more universal use, the same system may be excessively difficult to configure or install. The success factor is to keep interactions with users basically simple and user friendly – they have to be set up by sergeants, not highly trained integrators. An example was LINK11, which has five parameters to be set at installation, while its more modern replacement, LINK16, has more than 100 parameters. Sergeants who enthusiastically use LINK11, may suffer through difficult sessions to set up LINK16.

2.2.3 Collaborative Team Building

Simulated warfare operation to stress the metasystem is an important success factor because the system-of-systems will be constantly changing. Therefore, a leverage technology must be capable of constant involvement with users and stakeholders. It must be frequently placed into realistic stressful conditions. A key feature for success is to integrate the warrior interface, component development and system builder framework into a collaborative team. The team uses an operating framework consistent with constant "virtual combat." Stakeholders, system builders and component developers operate independently of one another, but collaborate in requirements definition and system building and testing.

2.2.4 Cognitive Overload

Systems must present information derived from massive amounts of data in a form that is easily understood by a wide variety of people. This is often stated as: "Tons" of data gained in the field require "machine" management of data. An example is that data collection technology can deliver 500 tracks, how does the user decide which ones are to be turned off or how to set up the system so it suppresses redundant information? Take an operational intelligence example with the capacity for 2300 reports per hour. It is typically easy to set up to get all this data, but very difficult to reduce this massive amount of data to useful information. In this case, there is little aid, or useful help function to guide the user. User considerations that make this possible are very difficult to express as requirements. In addition, human cognition requirements are often waived early in projects because they are difficult to measure and test. Applications that overload the user may fail to scale effectively in full scale implementations where human diversity comes into play. Rigidly canned applications, that may force a single expert's point-of-view on the situation, may miss critical field events.

2.3 Reengineering Warfare

The acceptance of advanced information use in the battlefield depends upon the way the military adapts itself to take the best use of it. One compelling reason for changing organization and doctrine is the downsizing of the military. We must do more (with less) because of downsizing, geopolitical change, quick in and out and the need for "no" casualties. To do this we must bring significant leverage to the individual in the field so a few of them can

handle the situation where many specialists were there before. Thus, one person must do multiple jobs, with less training. Information technology provides an information repository that allows warriors to perform with less detailed training but with increased access to information. Creative solutions must be encouraged and supported. This makes changes in military organization and doctrine necessary. This "revolution in military affairs" must take place concurrently in four areas:

- Technical
- Systems
- Doctrine
- Organization

Other success factors provide the means of system and technical change. This one is concerned with adapting doctrine and organization to maintain the full information advantage.

2.3.1 Doctrine Change

The way we plan to fight wars will be an important driver. The present military doctrine results in a vertical command hierarchy. In the past the military structure has changed very slowly, with generations going by between major change. When change occurs it is rapid because major shortfalls are recognized and there is a potential for dramatically improved results. However, there is little modern experience in how to rapidly change organization and doctrine. The Triservice environment also creates interoperability problems. There are serious issues when intelligence and operations might be integrated.

2.3.2 Acceptance by the Military Organization

Limitations are severe for the acceptance of changes in military organization and doctrine. Change in this environment is resisted because history has shown that it is difficult to introduce change in large scale organizations without risk of serious impact. These organizations often seem to operate by the book, but in reality they work because the people involved make them work through a supplement of informal methods. A significant hidden level of knowledge in organizational structures is gained though day-to-day conversation and training. Doctrine and tradition provide a reference framework but a major factor in military organizational success is gained though implicit and explicit training that is seldom captured in published form.

Major US corporations are now discovering that downsizing and reorganizations may not have served them well. Delta Airlines and NYNEX are examples [Economist]. They report serious problems in delivering the high quality of service that, before reengineering, was a leading competitive factor. The reason is the loss of tacit knowledge both in corporate memory and informal networks. These reorganizations focused on levels of middle management and supervisory personnel whose value may not be documented in the formal corporate organization. Some have linked the recent increase in Navy aircraft losses to the Tailgate

scandal that decimated the command level of pilots whose necessary experience had not yet been informally transmitted to others.

There are also anticipated problems of knowledge loss of in system building infrastructure due to government downsizing and corporate mergers [Crisp]. The Economist reported on a new generation of software for product data management, claimed to keep knowledge and improve against the impact of change. However, they also doubt that computers can mimic informal social networks that make up corporate memory. The challenge to making any changes to military affairs is to make sure that these informal channels are preserved during the process of acceptance of advanced technology into the military structure. Resistance to change will be significant unless the corporate knowledge can be shown to be preserved.

2.4 Creating & Integrating the Metasystem

The operational context envisioned for 2025 is a system-of-systems(metasystem). Dominant battlespace knowledge is the goal. With everything and everyone connected and interoperational, the hierarchies of theater command and control can all remain in the US during combat. Operations and intelligence might be merged. Each pilot, sailor or soldier becomes an observation point as well as force provider. The question, put simply, is "Can we build the metasystem." [1]

2.4.1 Interactive Complexity in Large-scale Systems

In a report on the Workshop on Engineering Systems in the 21st Century [Crisp], the ability of each operator to tailor his interface was pointed out to be a complicating factor. Instead, we advocate that it is a simplifying one. The complexity exacerbating case results if each operator interface is a variant that the rest of the system depends upon and must control and maintain. However, complexity is reduced to the degree that each entry point is independent. In that case, it is no longer a factor in the system state to be managed by the metasystem. A leverage technology solution might create the environment where every stakeholder is an active part of the system and responsible for resource consumption as well as performance. Computer technologists, as program managers, cannot bridge the gap across multiple disciplines involved in systems-of-systems. The problems of inability to communicate due to different semantics and semiotics will not be resolved without active user personal control and responsibility. Complexity will be significantly reduced only if the system builder is relieved from meeting requirements that can only be known in detail to the system stakeholders or user

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[1] If this integration of multiple information systems is accomplished, then the remaining trouble spots are those that are associated with non-structured, time delayed or disguised attacks—eg, invisibility of objects on battlefield, biological attacks, cruise missile (erratic flight, clutter, terrain masking, etc.) and concealed opening (underground) threats. There may also be difficulties when large numbers of refugees are present because they can mask military actions or block access. The assumption is that the enemy is sophisticated but can disguise its capability behind ordinary citizens. Thus, we may need distributed sensors and operational troops to gather and report intelligence at the necessary level of detail. In this case the diversity of attack increases significantly making personal control afforded by the Intelligent Exchange all the more important.

participants. The system builder is, in this scheme, responsible for timeliness and effectiveness with respect to constraints and budgets of each entry point into the system.

2.4.2 Understanding Human Communication within Metasystems

Users, stakeholders and developers of computer systems are constantly faced with the issue that consistent use of abstractions requires that they be an expert in another field. Otherwise they cannot truly understand how the mission is fulfilled from that viewpoint. Inconsistent use of information often leads to the same abstraction being used for two different elements of the system. Sowa gives an example where a major firm could not merge two data bases. In that case, the data base element "oil well" was an integral part of both geological and accounting data bases and meant fundamentally different things in each [Sowa]. A computer requirement analyst cannot become an expert in military matters and create a system that is truly realistic to a military stakeholder. Computer experts just do not have the long term opportunity to participate in a meaningful way. They have not gained the necessary mastery over in-depth knowledge. Likewise a military officer cannot become a superior computer analyst because he cannot gain the in-depth programming experience necessary.

What the analyst does is to become an expert in the elements of the military command structure that they believe might be successfully automated. The analyst does not deal with the remaining vast levels of tacit information and subtle knowledge that the military commander uses in making battle decisions. It is not feasible for the analyst to capture all this knowledge and put it into the system accurately and completely. Therefore, systems must involve every stakeholder in the system development by requiring a high degree of useful involvement.

2.5 Meaningful Communication & Common Understanding

Military organizations work because the participants have extensive training about doctrine and organization standards. The result is common understanding because of common experience. Even with this training, generation differences in meaning can arise between participants. In addition, military-to-civilian differences often make system building difficult. Thus, valid common understanding (semantic interaction) is key to this success factor.

2.5.1 Supportive User Interface Technologies

The voice, image and conferencing technologies that are anticipated in future systems are intended to aid this purpose. However, when systems are tied together by new forms of communication there may be additional conflicts in meanings. Formal protocols may be necessary to avoid communication difficulties and loss of understanding between humans of different disciplines. If one is not capable of carrying out the action, then the words about it lose accuracy. Training and continued person-to-person activity in the military allows for a greater accuracy than a conservation between strangers with totally different backgrounds. However, during a period of revolution in military affairs, the opportunity for inaccurate communication is significantly increased.

2.5.2 Accurate Understanding of the Battlespace

The success factor of building the metasystem is closely related to fundamental philosophical issues in computer science. Since "reality" is represented electronically, the machine's results may not reflect reality or may not provide complete and consistent viewpoints among the users. Small errors or misinformation in these representations may undermine fidelity and, as a result, cause loss of confidence and trust of the system. Different understanding of battlefield situation by various stakeholders is a common and serious problem. The conclusion of the Gulf War is an example. In this case the maximum impact of the victory was lost because the President, Joint Chiefs, Theater Commanders and Generals had a different understanding of the battlefield situation.

A related problem is that a logically centralized metasystem might be a damper on originality and individual actions. Creativity is cited as a significant leverage in warfare. An example is the 1967 Israel/Egypt war, where Israeli forces were unprepared for wire guided antitank missiles, but quickly changed the related doctrine to win the war. In military archives there are a number of other examples of wars being won by rapid and creative change to doctrine and organization or through individual action outside established doctrine. Centralized information control may prevent the necessary insight and capability needed to recognize an opportunity and take a creative action. Computer/communications systems may not report the data needed for conceptual leaps because the designer cannot anticipate the need for the data path.

Another problem is that sharing of information may bring operational problems. Deciding what to share is an issue if intelligence and operations merge. The access rules and conditions—eg, can someone be fully informed about high mortal danger they are soon to face? For those who advocate a centralized control, a metasystem constraint is that many real time control requirements cannot be centralized. Delay due to satellite transmission of ¼ second is too long for long distance weapon control. Therefore, central planners, directors and micro-managers cannot take control of all reaction. Other possible delays due to system or communication latency are present.

There are major differences between past and present in how communication channels can be used. The simply coded single phrase messages of the past may be replaced by voice and image transmission. Improvements in small scale cases usually result. This is because the participants typically know one another well. However, the use of voice and video face image may exacerbate the difficulties of small system demonstration versus large system fielding. The coded message provides less information but it gives a very clear command. As more people are brought into the sharing of information the opportunities for miscommunication and misunderstanding may increase. One reason is that voice or images may infer a different context for others, leading to different understanding of informal and casual remarks. Mountain climbers have a formal set of voiced messages for ensuring safety and attention. Likewise, military users will need to maintain a fixed protocol alongside new communication forms provided by the addition of voice and images.

2.5.3 Wide Diversity of Humans in the Loop

The mixture of humans involved in future operation will be wide. Coalition forces are expected to be the most common mode of deployment. There will be questions about how much

information to share because today's ally can become tomorrow's enemy. Also there may be a widely varying mix of language, skills, decision processes and nuances among participants. Training can help to avoid miscommunication. Warfare simulation is expected to prepare US and allied force combinations.

Situation simulation (of future warfare) may have up to 20,000 units involved. Distributed interactive simulation may provide a realistic feeling of actual operations. (Some experts have doubts about the value of simulation because it is too predictable.) Users need hands-on experience to make useful applications of data and to spread knowledge about the meanings of new displays and data. The necessity to "put data into the hands" of a diverse set of warriors was a stated success factor. This implies using accepted forms of display that match a broad majority of Warriors. In order to gain the confidence of humans in the loop, new systems must dovetail with the infrastructure. New systems (and organizations) must be incorporated into the simulation to provide a transition from the old system.

2.5.4 User Identification and Trust

A success factor is the capability of positive identification of each participant by the system. Once identified, the system would respond the way the user expects and at the technical level best suited for him. The response would change with the situation and location. With experience the individual would build his trust and confidence in the system. Also, as he interacts with the system, others will recognize him and interact accordingly. A significant effort may be placed to ensure that the system operations are proper for the role and situation of the user. In addition, the force is expected to include coalition forces, which may have more limited access.

2.5.5 Transforming Data Masses into Information

There will also remain a semantic gap between each individual in the system. Some gaps will be small because two individuals have a common heritage and training background. Other gaps will be large because of widely varying views of reality. Vertically oriented (stovepipe) systems are a natural consequence of the inability of the analyst and stakeholder to understand the needs beyond immediate needs and issues. Going beyond a narrow domain may have made the system impossible to specify and build. The way each user best understands a display can be widely different for different users. A necessity is putting data in a form that is consistent with the user's experience, education and training. In the military the levels of experience are maintained as closely as possible at a given level. This success factor requires that the system have a recognition system can identify the user and respond according to her preferred methods. This would reduce conceptual loads on the user.

2.6 Success Factor Summary

These success factors intensely involve multiple user types and their interactions. These include: stakeholders, warriors, integrators, operators and vendors. Such personal involvement causes complex interactions that require a high degree of user control, functional flexibility and system robustness. The high degree of people-to-computer interaction, across

each of the success factors, points to the need for managing humans and interactions among humans as being an overarching necessity in 21st Century Metasystem visions.

3. The Warrior's Personal Decision System(WPDS)

This chapter focuses on the flexibility aspects of personal control. This overview gives the Warrior's viewpoint and needs in a flexible, incrementally developed battlefield information architecture. These solutions require a persistent involvement of the warrior. However, they accomplish the flexibility necessary to give the warfighter the ability to define his individual information environment. Note that the success of the flexibility solution to complex systems depends upon frequent exercise and use, sometimes even in a full scale manner. This use defines the capacity necessary deliver full capacity during combat. In addition, constraints are enforced by the WPDS to give (and take) the authority of warriors to collect information, make decisions and act based on their personal decision system. The result is that the command structure has confidence. This confidence is the best kind, that gained through frequent involvement and use.

3.1 The Warrior's Information Battlespace

3.1.1 Warfighting Mission Background

The Defense Studies Board Summer Study Task Force Report on Information Architecture for the Battlefield found that information technology gives significant advantages in planning and carrying out warfighting missions [DSB94]. They concluded that any information system for warfighters must provide a high degree of information access flexibility.

> *"Information warfare has become critical to the way nations fight wars" [Fogelman]*

3.1.1.1 The Warrior as the Information Consumer

The military is just beginning to understand the full advantages of making "the warfighter the information consumer." Also the opportunities and difficulties of faster information transfer time cycles for information collection, generation, delivery, fusion, and digestion are emerging. The key leverage is in delivering it to field, wing or ship commanders who have the situation-specific knowledge needed to make more effective decisions. By allowing an on-the-site warrior to make his own decisions, latencies created in centralized coordination systems are avoided. High confidence in decision critical information is a necessary element of these systems. When users become dependent upon them, the importance of consistent operation and robustness increases significantly. Safety, security, availability and reliability are necessary elements. However, having them makes it difficult to achieve flexibility and timeliness.

3.1.1.2 Shrinking Battlespace Time Frame

In addition, the battlespace time frame is being shortened. The necessity for rapid decision making may limit centralized command posts to general, longer range plans, objectives, policies and protocols. Thus, the distribution of pertinent information and situation awareness to the warfighter is critical to each decision and action. The collection of information and its dispersion significantly changes and enhances the command legacy information and command flow. Thus, timeliness is often more essential than robustness.

3.1.1.3 *Evolving Warrior Roles*

Over time, as the means to address levels of detail evolves, the term "Warrior" will take on different meanings. In the near term a Warrior would be a regional command officer who wants to redirect a mission to respond to a newly discovered target or threat. In the distant future, a Warrior might be a pilot needing to react outside his planned mission, using voice commands to address the personal decision system. In both cases, the increment of information provided by a WPDS would allow increased freedom in responding to targets of opportunity unforeseen when the mission was planned.

3.1.2 Airspace Sensing Example

Assume the Warrior is a sergeant responsible for identifying threats in a hostile air space. After noticing a repeating pattern of activity that combines information provided by satellite images and radar reports she associates this with enemy activity that has threatened our new pilotless, ground-piloted drone attack aircraft. She uses her WPDS to review other activity in the same time frames—eg, radio transmission intercepts, other satellite spectrum images, etc. If she sees a pattern, the WPDS gives her the capability of naming and characterizing the pattern and time period. She defines also the action to be taken by the WPDS when this event occurs. Perhaps, during an exploratory period, she would simply be notified so she can refine her observation. Since events such as these are subject to interpretation, she must establish statistical decision levels about the images, radar reports and radio intercepts. To better understand them, she communicates her results to experts in the field who provide their knowledge through a shared knowledge space. She understands the local situation best, while they understand the sources better. Once the shared knowledge is set up, it is kept consistent by the WPDS. If she changes the way she uses an image interpretation both she and the knowledge sharing expert are notified and required to agree upon the expanded definition.

As the event detection matures, both its decision processes and robustness are improved. Through frequent use, event detection becomes reliable enough for her to teach the WPDS to act on its own—eg, rapidly notifying her command of the enemy threat. As the sergeant works out the response and defines its actions, a projection is made in the context of larger scale coordinated activity. The result of this projection may make the WPDS force limits on what can be done. Assume, in the example above, that the pattern of activity by the enemy was one that higher level command wished to continue. Perhaps it is a means of trapping the enemy into revealing larger scale plans. The WPDS, with its constraint based controls and situation communication, could ensure that the sergeant's WPDS knows not to proceed further with an action that might let the enemy know his activity had been detected. This control could be communicated to the WPDS and it would ensure that silence is kept on the topic. Note that the knowledge sharing experts are in the loop and can suggest this new sensor correlation amplifier to other sergeants with similar responsibilities. The key feature is that no one else but this Warrior is in the right place at the right time to notice the unique combination of events that led to this unique tool.

3.2 Requirements in 21st Century Warrior Systems

The airspace sensing example shows the need for a capability to warn, limit, and constrain the warrior with respect to doctrine, command authority, on-going action plans and other organizational constraints. In WPDS the warrior is allowed to make decisions and take deviations from his previously planned activities. The capability to adapt these constraints as organizational and doctrinal change is a critical need.

3.2.1 Operating Models

3.2.1.1 Event Identification and Detection

For the operator, personal control means providing the capability for him to create new functionality. One that notifies him of unrecognized or serious events. Then it lets him create the system operations necessary to respond. It also helps him to set up training for his entry point to recognize and make the proper response in the future. This capability lets the user maintain or improve interoperability. It requires knowledge-based systems for structuring networks and computer systems for reducing the training level required to get reasonable performance and useable results without intensive training. An additional challenge is giving the users the ability to create automatic verification and testing scenarios that measure these improvements. By collecting feedback from these users a knowledge base can be generated for preserving infrastructure and interoperability capabilities.

3.2.1.2 Battlefield Situation

The related need is faster recognition of battlefield situation upon presentation of new information. Warfighters often operate in such a reactive mode. Systems that are geared to maintaining informal interchange between involved persons seem to be a critical function. For example, distributing an advanced command and control system by relocating commanders and operators to multiple disjoint sites can lead to communication difficulties. This can be unsatisfactory because participants are too isolated to chat and discuss informal operational and robustness issues. The solution often requires that the command post and participants be centralized to ensure that chatting was easy and informal. This keeps the human's tacit interchange level high, allowing for better understanding of the situation and each other's decision processes.

3.2.1.3 Coordinated Action

The worst nightmare is when local opportunities or directions are taken which prevent the successful execution of high level commands or global plans, actions or strategies. Giving individuals the capability to understand the battlespace situation, decide upon a course of action, and execute it does not mean that authority and regional plans of the higher level command are not considered. In fact the intelligent system needs to take those into consideration for the participant, guiding them away from actions detrimental to the whole. Yet, a common understanding is necessary between the parties before the conflict between

actions is obvious to the system. A means of validating commands and decisions across these hierarchical boundaries is needed.

3.2.1.4 *Understanding Authority*

The expected difficulties are in the capture of the meaning of authority and command and storage into computer understandable terms. A significant amount of officer training consists in ensuring that orders, regulations, commands and other context and tacitly understood material is consistently understood by all. Likewise, the understanding of the general and local situation by the WPDS is necessary. Capturing these meanings into a computer-based system requires a powerful decision mechanism and trainable knowledge base. These would be used to project proposed warrior actions to verify that they remain within the constraint model's boundary. Once that is accomplished, an intelligent mechanism is needed to match the anticipated results of the warrior's plan and verify that the authority and general situation are not violated.

3.2.1.5 *High-Confidence Measures*

High confidence measures for robustness—ie, safety, security, availability and reliability—are necessary in support of the warrior. Confidence in the information and decision making by a WPDS is necessary for true involvement of the warrior. Without confidence the system will not be used near its potential. The safe synthesis lets the user define mission function component harnesses to match his needs under different mission situations and time periods. He then selects levels of robustness without the necessity of understanding the robustness implementation.

For example, the user could define a core set of information functions with high robustness during certain phases and low robustness during others. In addition, the user could schedule the information to provide background information updates or infrequently changed information, such as terrain maps for tomorrow's expected situation. A crude level of robustness might be handled by the user simply requesting the information a second time if it was not received. User-centered control offers a significant optimization since it is demand pull.

3.3 Warrior-Centric C^4I Systems

Historically, C^4I applications bring information to the top level and distribute commands back to the lower levels. The information age has brought a significant expectation of change in this organization. "Making the warfighter the information consumer" requires that information flow in myriad directions, across services and service specialization. Also, information fusion is necessary at many locations. This new information will enhance the legacy hierarchical flow, which remains as the backbone. However, the individual warrior can now receive information that is important to his personal needs.

The user's capability to configure his own personal decision system requires new system design approaches. To some degree the WPDS research must deal with this complexity in a new way, without rigid assignment and allocation according to preconceived notions of what warriors actually need for every situation. Warriors build their own decision system over time

to reflect their needs. The designers provide a framework within which the warrior can assemble her personal decision system. Flexibility in taking personal control is the critical need for the Warrior's successful and effective use of C^4I resources in 21st Century Metasystems.

3.4 Providing Flexible Personal Control

In the WPDS model, a human is responsible for refining each interface and uses a high degree of flexibility in arrangement of services to fit his needs. Intelligent interfaces might operate as automata with certainty about the decisions they make because they have been trained by the user. However, Intelligent Exchange automata depend upon human training and creativity when they reach impasses about events, situation or course of action. The user has responsibility for improving the operation of the intelligent exchange. Both training and expression of knowledge are first made during training practices. The mastery is eventually refined through frequent use and after full-scale simulated stress.

To accomplish this interface role, the Intelligent Exchange would be capable of being taught what is common and repetitive. It would allow the user to set up the event recognition and an automatic reaction to it. If present trends continue there will be a number of multimedia information types. The user should be able to control the detection of events that combine information from a number of these. User interface tools would supplement the Intelligent Exchange, allowing it to match operational methods. To provide the flexibility with confidence necessary for the Warrior the WPDS requires the capabilities defined in the following paragraphs.

3.4.1 Personal Control Focus

In the WPDS model, all external and critical system interfaces have an adaptive interface that provides limited-context, intelligent operation of interchanges between various system elements, including humans and human-coupled organizations. Human system operators and maintainers are the focal point of flexibility provided by the WPDS interface. The interface is built as an intelligent component that detects and fuses common events into recognized situations. It then reacts automatically if it understands the context and case. In addition, it is adaptive to handle change. A human is expected to train it to respond to "new" discoveries found in the interaction or information exchange. New systems would incorporate the interface internally and with each external interface necessary to legacy systems and organizations.

This requirement results in the Personal Control User Interface. The Personal Viewpoint & Mastery and the Extensive Decision Surface elements of the Intelligent Exchange are a partial result to this requirement.

3.4.2 Flexibility Advantage

There is only one person that can define a warrior's needs accurately and precisely – the warrior himself. The solution offered is to relieve the system and software developer from this impossible and changing task. The WPDS creates a shift from developer-centric to warrior-centric systems. The change frees system designers from resource rigidity, allowing resources to evolved to meet the warrior's needs.

The WPDS gives the warrior the following: flexible choice, high confidence, and robust reception of the information required to perform her mission. A warfighter-centric approach lets each individual choose and collect information that suits her particular situation, level of command, and role. To be complete, the system would have generic warrior knowledge templates for battle actions, logistics, personnel, intelligence, aircraft, etc. The WPDS would add a level above each domain's generic knowledge base or canned expert associate. Constraint-based controls ensure that a warrior does not exceed his delegated decision authority and does not negatively impact the overall command-wide mission.

Each role player will be able to select information components and data server accesses corresponding to different situations. In the operational scheme, the individual warfighter builds a personal decision system from a library of information system components, connecting outputs to inputs and setting conditions and schedule for execution of the components. The user may also set the required robustness on a component by component basis. To prevent excessive demands, the system would intelligently and automatically restrict choices to correspond with resource capacities.

3.5 Flexibility Through Choice and Synthesis Capability

Giving a Warrior the flexibility to individually choose components to formulate his own personal data mining, information fusion and decision support, can significantly add leverage and advantage to his actions. The Warrior's Personal Decision System(WPDS) provides flexibility and adaptability to warfighter information systems. The Warrior would use an interface that allows him to choose among information system components. Yet an intelligent constraint mechanism guides his choices to ensure that the Warrior stays within his delegated authority and resource capacity limits. This pairing of flexibility within constrained safe limits is a key concept of the Intelligent Exchange, which is introduced later as the leverage technology.

It must be made clear that the flexibility afforded the Warrior allows him to define information events within the system that involve time slices and combinations and patterns in imagery, multimedia, text, graphics, tables, etc. This access is to be afforded by manipulation at the user level – he is not expected to be a programmer. In addition, the resulting combination must be "computationally" safe – ie, cause deadlock or excessive memory use, or permanently lock up resources. Also the Warrior must have a means of browsing capabilities to discover these opportunities. Such a capability is an extension beyond the present capability found in visual programming languages and other object environments (or in Web search tools). The assumption is that the system provider and programmer cannot know what the Warrior might need or even what might be available.

3.5.1 User Synthesis of Functional and Robustness Components

In the WPDS, there are components and harnesses that are used for functional purposes. They are combined by the user to create a hierarchical function set for the mission function. Each interface between components in a system is supported by a smart interface. Likewise, robustness operations are provided within the system through harness assignment. This

isolates the operational robustness issues from the functional one and is the first stage of complexity management.

The WPDS design must separate function, operating robustness, and response delay issues. Prevention of overload of the system by excessive user demands is also provided by the WPDS. In addition, the WPDS must provide a means of collaborative communication between the user, component builder and system builder elements.

The requirements are:

- Provide capability for warfighter to find and compose an information gathering and decision system from available components. Multiple warrior roles are necessary to immediately meet situation decision information needs at all levels of command—ie, provide commanders and warriors at all levels with required information as they specifically request it. This will require a well-understood component library with user control at the right level of detail.

- Provide the capability for ensuring robustness while maintaining confidence in overall system timeliness. Give users the capability to choose robustness levels consistent with their immediate needs, possibly getting information faster but at the higher risk of faults or compromise. This gives an assured operational robustness level—recursive high-confidence harnesses (with separation of function from safety, security and availability measures, allowing the user to simply assemble a functional harness)

These requirements lead to the Safe Synthesis and Robustness Services element in the Intelligent Exchange.

3.6 User Confidence

The user keeps high confidence because they "dial and connect" components to build both mission functions. They only need to choose a level and parameters to obtain system integrity (robustness) levels for safety, security, survivability and reliability. Off-the-shelf components (reusable) for mission operations and for system integrity components would be available. When components are lacking, the user communicates with a development team to find or add new components. "Dialing and connecting" is an operation that includes setting a time cycle, as well as defining dynamic responses to the warrior's defined events. The user may also define system robustness (integrity) levels with respect to mission functions and system or situation states and events. Each mission function has a full definition of time periods and time responses based on system events. However, warriors will unexpectedly demand information, yet they cannot be expected to predict the impact of their choices on overall system time response and robustness.

The warrior would be expected to develop his WPDS in a reflexive mode—ie, during simulated combat or lulls in battle, defining observation, decision and response. During simulated combat the warrior would use the system in both reflexive modes to build knowledge and make plans and to practice reactive modes, allowing him to respond rapidly to battle events. Alas, during

simulated warfare the elements of creativity afforded by the WPDS are less well played out. For example, the air space sensing example would not have unanticipated patterns. If they were a known part of the simulated training then they would have likely been already included in the sensing repertoire.

3.6.1 Ensuring Compliance & Conformance

Each WPDS interface is located solely at its entry point in the system and is not distributed. Information about the systems and associated models and states is communicated by a distributed component that operates as a communications and computational background. This a system-state feedback that also provides the mission situation information. The WPDS interface is primarily concerned with making the metasystems work at a reduced level of complexity. In the mission function case, a different human role would develop and train the system WPDS to perform mission functions.

The WPDS approach to complexity reduction includes building a cost and response model that prevents the user from going beyond an allocated resource consumption level. The entry points action automatically imposes resource capacity constraints that limit the user's selections. This ensures that the information demand matches the underlying system's capacity for effective performance.

The requirements are:

- Provide the capability to warn, limit, and constrain the warrior with respect to command authority, regional plans and constraints as far as they effect warrior decisions and deviations from reported and planned activities. The capability to adapt these constraints as organizational and doctrinal changes take place is a related need. This requires a mechanism for coherent operational context. This gives a user a consistent understanding of the situation with that of the command's actions and plans. In addition, the mechanism must provide a means for logical time synchronization. Time synchronization ensures that the user has timely, valid or useful data.

- Prevent overload of the system by excessive user demands. Build a limiting cost and response model function that prevents the user from going beyond an allocated resource consumption level. Automatically impose time response and resource capacity constraints as limits on the user's selections. This ensures that the demand is within the underlying system's capacity for effective performance. This requires system communications and computation delay and capacity models—predict impact of capability requests.

These requirements result in the Confidence Constraints & Models element of the Intelligent Exchange.

3.7 Creating a Coherent C⁴I Operational Context

The C4I operating context is a highly unpredictable and dynamic environment. This means that it must have a general and platform independent programming model and interface. The

WPDS version sets up a shared object space and execution threads that are available as a virtual processor. The threads are activated by control events and data validity and availability communicated through shared objects. Central control is minimized because each node performs a synchronizing control model. During robustness operations, there may be duplicates made of these threads and duplicate data distributed to other nodes. A harness object controls the robustness operation. Note that the object space must span individual distributed operating systems, as the URL does in the HTML programming language, but be safely operated on symmetric multiprocessors.

Coherence is obtained at the cost of introducing time and state control frames that set the validity of synchronization objects. Each time cycle has a set of time frames within which the mission scenarios are defined. These time frames are used to ensure a finite number of system states. Some tasks are latent, waiting for events and state conditions before they are activated during a time frame. During each time frame the nodes in the system execute a "bag" of threads that are activated and allocated by the run time system. These threads interact based on synchronization signal validity or data validity. Conditions within the system are captured and communicated to the requiring node. These create events based on conditions (state or situation) that become valid within the time frame. (State refers to the condition of the system components and situation refers to a condition of the real world mission.)

The requirement is:

- Ensure that the operational framework fits the C^4I operating context, with wide ranging, dynamic resource demands yet with constant operation over a twenty-four hour, seven day basis. Ensure that today's software, where the investment is, is not compromised when computational and communication capacities change with hardware and system upgrades.

This requirement leads to the discussion in Appendix A – General Technology Needs in Warrior Centric Systems.

3.7.1 Integrating with Operational Readiness Activity

Operation and maintenance are Warrior activities that can use the WPDS to high advantage. By having each interface in the system have an operator that can continuously improve the operation of the interface the problems that arise from change in systems will be on a long time basis. Training the system during full scale simulated combat and getting the operators involved on a long-term goal basis would allow the metasystem to better server its Warrior users. The result of achieving these capabilities is that a system based on the WPDS has a significantly reduced complexity. Warriors select what they want from decision system components. Component builders build components to meet needs defined through feedback from the warriors' experience. System builders have a quantitative means of improving their system effectiveness. Thus, the divisions of responsibility match the expertise.

The requirement is:

- Integrate a warrior interface, component development and system builder framework into an operating framework consistent with constant "virtual combat." Involve the warrior as a stakeholder in the system by requiring a high degree of useful involvement and use. Provide warrior feedback to component developers to ensure a constantly improving mission.

3.8 Limitations of this WPDS Example

Note that the WPDS requirement discussion concentrates on the control over the Warrior's personal mission demands, associated confidence constraints, robustness services and the situation communication. The leverage technology also requires addition sophistication of mechanisms for consistent interaction, expression of personal viewpoint and mastery, reactive decision making and a mastery reference base. The Intelligent Exchange, discussed in the next Section, provides a more complete and balanced description.

4. The Intelligent Exchange—A Description

This chapter describes the elements, associated support mechanisms and general capabilities of the Intelligent Exchange. The Intelligent Exchange has the goal of providing the personal control necessary for professionals to create a "mastery" assistant within the metasystem. By this we mean that each professional builds a knowledge base and reaction tool that overlays the knowledge bases and information systems found in the metasystem. The personal mastery system operates with respect to the user's detailed knowledge and operational direction at his deepest level of expertise. As the mastery is refined, the professional user teaches the Intelligent Exchange to incorporate the new event, reaction, knowledge or process.

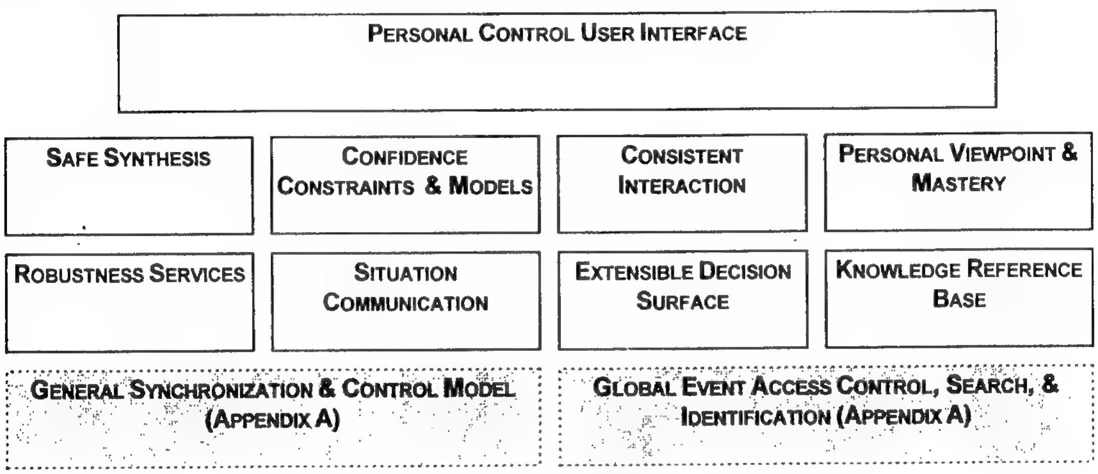

Figure 4-1 — Intelligent Exchange Layers

For the Intelligent Exchange's personal control to be successful it must be adequately powerful, yet not threaten the organizational command structure or smooth operation of the metasystem. A base of personalized knowledge is kept that represents the special knowledge of the user. It must provide for effective and robust delivery of results, yet be set up and controlled without detailed computer science knowledge of formal high-confidence methods and programming. In addition, information shared with others must be kept consistent with each user's personal viewpoint. The necessary technologies are shown as the first three layers in Figure 4-1 — Intelligent Exchange Layers.

4.1.1 Personal Control User Interface

A flexible personal control user interface is the integrating framework at the highest level. Here the viewpoint is the portion of the information and the method chosen for viewing the context. The user can set this so he can ignore mundane and repetitive observation and reaction. Personal control is the key. Users must be able to access, using human computer interface means, the details of computer presentation, visualization, sensing, data fusion, processing and decision making and put together a perception and reaction related to heterogeneous combinations. This amalgam expresses the user's personal knowledge and reaction response to

the degree it can be expressed by a computer. An assumption is that the personal control layer will take advantage of the most advanced speech, gesture, 3D context (virtual reality), and visualization techniques.

4.1.2 The Personal Control Interaction Layer

The elements in the personal control interaction layer are those that the Warrior controls using the Personal Control User Interface. The four primary operation control level components are:

- Safe Synthesis—refers to the ability of the user to create combinations of functions and operations.
- Confidence Constraints—refers to the measures taken to constrain users from interference or cross purpose with plans, doctrine, other organizational issues or military or information system resource limits.
- Consistent Interaction—refers to a personal context that the user interacts with by making choices and changes. The personal context is interfaced to a number of shared contexts, with the means to negotiate meaning with other users. Changes in personal context are verified to be consistent with any shared knowledge.
- Personal Viewpoint & Mastery—refers to the capability to explore, create and observe a personal knowledge reference base that includes data, relationships, symbols, reaction, and history.

4.1.3 The Support Mechanism Layer

This layer is controlled by the actions taken by the user while interacting with the interaction layer. Each element of the Intelligent Exchange's personal control has an underlying technology that must come to fruition to give both the power and acceptance necessary. These are shown in Figure 4-1—Intelligent Exchange Layers. The support components are:

- Robustness Services—refers to reducing the complexity of safety, security, availability and reliability so the warrior can build complex applications without concern for formal high-confidence methods. They are expected to be provided by the system builder.
- Situation Communication—refers to passing state and situation information to the metasystem entry points that need it. This is provided by the system so the user's decision system has timely models, goals and information.
- Extensible Decision Surface—refers to a powerful and extensible decision making mechanism that can decide, based on teaching by the user, about what is happening in the system and what to do about it. It must be capable of being trained to perform this across a wide range of creative uses.
- Knowledge Reference Base—refers to the mechanisms necessary for keeping the personal mastery reference as it is built, defined used and modified by the user.

4.1.4 General Foundation Layer

At the last level (shaded boxes) are the general technology foundation mechanisms for synchronization control of knowledge bases and information access. The system foundation upon which these components are built is shown in the lowest layer. Any successful metasystem depends upon these two components:

- General Synchronization and Control Model that allows the Users to harness components.
- Global Event Access Control, Search & Identification that is a means of finding, accessing and controlling remote components.

(These are discussed in more detail in Appendix A: General Technology Needs in Warrior Centric Systems.)

Not shown is that the common knowledge provided by knowledge based systems, information systems, and various intelligent associates that are planned to be provided by the time the Intelligent Exchange could be fielded. The Intelligent Exchange is a veneer of personal control, represented by synthesis, confidence, consistency and viewpoint technologies, that is placed on top of these common tools.

4.2 Intelligent Exchange Diagram

Figure 4-2—Entry Point Application of Intelligent Exchange Capabilities—shows the relationships among the elements of the Intelligent Exchange.

The Intelligent Exchange is an entry point between the user and the metasystem. Personal control is given by the capability to decompose, recompose and vary the viewpoint of information and knowledge functions. This allows the user to create a personalized entry point explicitly for their mission command, operation or support function (Personal Control User Interface). The user must be made capable of accessing the external system and identifying the capabilities and components available within the metasystem (External Metasystem Operations Interface). Extensions to commercial browser agent technology are likely to provide an excellent tool for this (Remote System Interface: Global Event Access, Control, Search & Identification).

The personal control extends to access to information and components and harnessing them together at multiple levels of detail to produce new information without detail level programming tools such as compilers and debuggers. A visual scripting language with a general synchronization and control capability is needed for both the local client computer and the server. At the entry point, significant aids for encapsulation and operational verification of the harnessed applications are necessary. The user can harness together data, images and events to create a new event perception (Safe Synthesis). The user's plans and activity are limited to operations that conform to higher command goals, plans and activity. In addition, the user is limited so he cannot overwhelm the system resources (Confidence Constraints & Models). The internal access needs to be even more powerful and allow the Warrior user to access devices and multimedia sources (Local Operating System and Hardware Interface). Personal control means that the user can change the presentation of information by setting up a

particular viewpoint of the mastery and knowledge data base (Personal Viewpoint and Mastery). This viewpoint extends to clumping of knowledge into new symbols and compression of display volume and complexity and storing them for later access (Knowledge Reference Base). This lets the user control the computer's presentation within his cognitive bandwidth. For example, signal transforms would be components that change how information is represented. He then teaches the computer the proper reactions by identifying and connecting objects with synchronizing logic and time controls. Thus, a powerful but flexible event detection and recognition service is provided (Extensible Decision Surface).

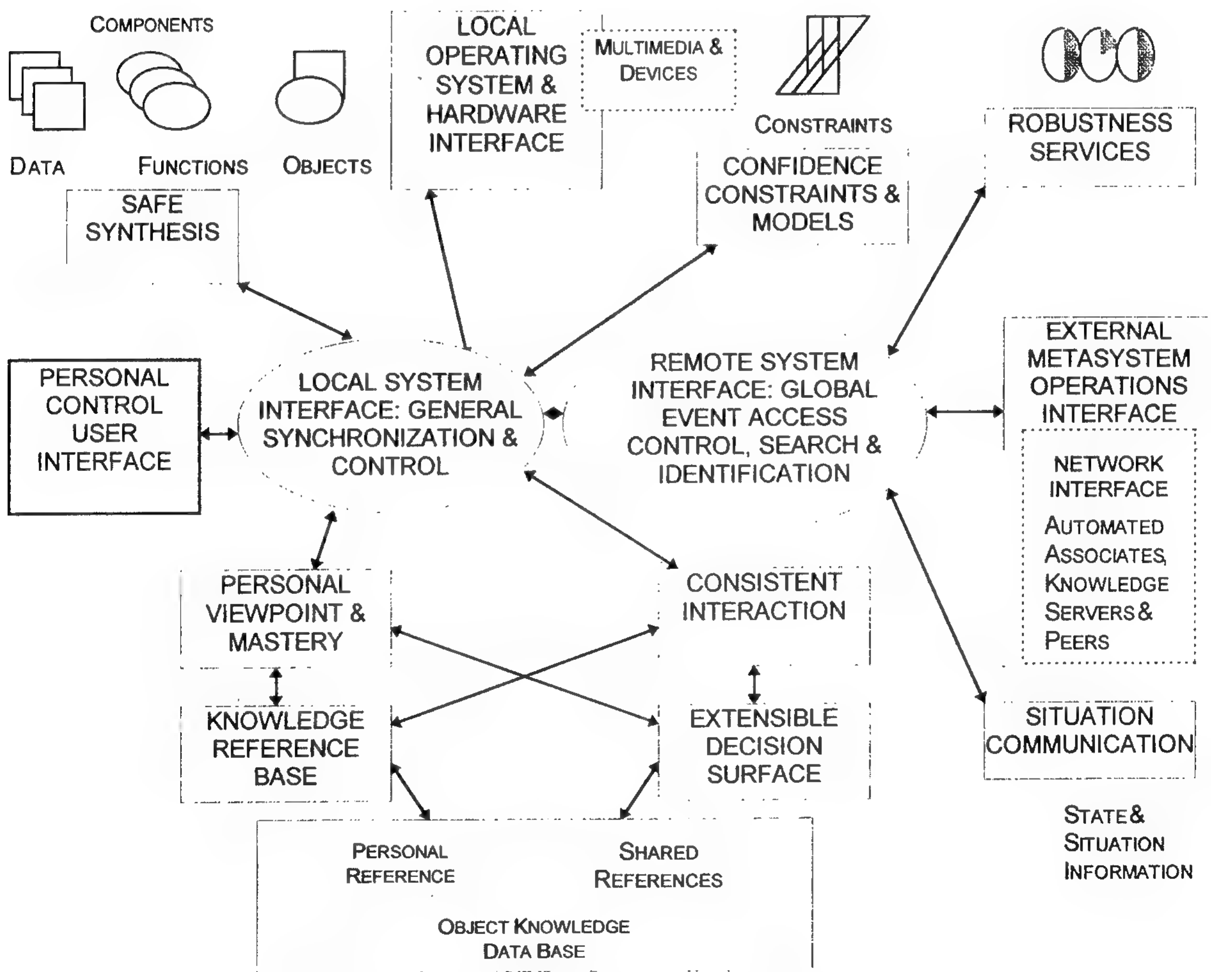

Figure 4-2—Entry Point Application of Intelligent Exchange Capabilities

The Intelligent Exchange keeps the use of this information consistent over time. In addition, information shared with others is controlled to keep it consistent when the user attempts change their personal mastery and knowledge base. Automated tools for computational safety analysis and verification aid the user in this operation (Consistent Interaction). Other entry points cooperate within the metasystem to provide some of the information necessary to make

these decisions (Situation Communication) and also perform integrity operations (Robustness Services). This means that each user's entry point provides these services for others in the metasystem.

4.3 The Interaction Layer—Personal Control Capabilities

The addition of personal control over the functions, operations and knowledge base to the users' capabilities, requires that four intimately linked capabilities be built. These elements are those for Safe Synthesis, Confidence Constraints And Models, Consistent Interaction, And Personal Viewpoint & Mastery as shown in Figure 4-2—Entry Point Application of Intelligent Exchange Capabilities.

4.3.1 Safe Synthesis

The Safe Synthesis data, function, object and robustness controls are synthesized (correctly fused) into synchronized execution strings. This creates a harness that follows the user's information requests, including the requested robustness levels. Further levels of robustness are gained by encapsulating the initial "fused" information function and robustness harness. This recursive synthesis creates a new set of execution strings.

The synthesis component separates information functional components and robustness non-function components, allowing the use of harnesses that fuse them together. The user defines the combination of information system functions necessary for their individual mission. An execution image is created for each user defined assembly that consists of execution strings coordinated and synchronized by user defined logic blocks. The user requests a level of robustness by setting parameters. However, the robustness level must be provided as a service by a support layer in the metasystem. The user can request the lowest degree of robustness that is acceptable with respect to the confidence constraint capability. (Some robustness measures may also be automatically overridden by the confidence constraint capability.) A scripting language extension enables inter-component synchronizing operations both externally over networks and internally in any type of parallel computer.

The long range vision for Safe Synthesis is that the user also defines flexible selections to match their needs. These needs change under different system conditions, for different time periods, for different points in an overall plan or for different system loading. In addition, the user could schedule in advance background information updates for infrequently changed information, such as terrain maps. Robustness for background functions might be handled by the user simply requesting the information a second time if it was not received, significantly reducing the system load. User centered control offers a significant optimization since it is demand pull.

4.3.2 Confidence Constraints & Models

The confidence constraint and model element includes constraint and projective simulation models. These models are coupled to controls to prevent doctrine violation, command interference, cross purposes, endangering friendly forces, or resource capacity violations. The actions that would result from an activity "proposed" by the user are projected over time and compared to models of these constraints. If inconsistencies are found the user is informed and

assisted in correcting the activity. Note that these models and their present situation are provided by a distributed background function that maintains and shares order, situation and model knowledge (See Situation Communication).

In the long run the system engineer must integrate computer and communication capabilities according to the technology and external systems available. The integrator's job has been difficult when the demands on these resources are dynamic and not predicable. However, the goal is to give the individual user flexibility in demanding information. Thus, the system engineer uses estimates based on very little operational knowledge. He may not have estimates about when the information functions would be demanded, where they would be "fused," or what parts of the system are to be used.

The solution is to use resource allocations and unused capacity to provide the user with application and robustness choices, but limit these choices to stay within consumption and confidence constraints. The user can select the function and robustness level to meet his own immediate information needs. However, the user is limited in resource capacity use by imposition of constraint controls and cost models. The long range view is also that a model of operations could be extracted from the user's demands and rejections by the system builder team. This allows users to train and adapt their personal information requirement templates during realistic system loading and the system builder to gain the information needed to evolve the capability necessary to meet user needs. This can only work if the system is used frequently in realistic, virtual combat because stressful conditions are a necessary test.

4.3.3 Consistent Interaction

The Intelligent Exchange must enforce consistent meaning during development and operation. Operating and building intelligent information systems requires consistent meaning on all the types of stakeholder experience (roles) involved. Role-players must be able to consistently understand the abstractions of other users, yet cannot be expected to have the full depth of experience of each of them. Once built the Intelligent Exchange must provide the users with viewpoints they understand, and avoid information overload and false or inaccurate abstractions.

The Intelligent Exchange solution is based on a robust and inexact decision surface and context storage that forces decisions about observations. These lead to insightful additions to the experience base. However, the resulting knowledge context base can be highly flexible. New meanings may be introduced as long as they are consistent with shared information base. The knowledge context base is much more than a vocabulary, it represents the relationships of the experiences across the boundaries of role-players. Thus, an Intelligent Exchange is the core component in collaborative systems that can give users an accurate and meaningful communication of specific experiences expressed as complex object diagrams. The Intelligent Exchange provides understandable experience expression because personal viewpoints hide unnecessary complexity – ie:

> *"Our ability to convey meaning depends on two things. ... an established, shared vocabulary ... and we need to employ that vocabulary in a distinctive way, impressing our meanings – ...ourselves – upon it. ... computers ... are exchangers of information,*

not meaning; ... Accuracy in communication can only exist in the presence of some meaning, otherwise, nothing is communicated." [Talbott]

The consistent interaction component verifies consistency of observations with the mastery and personal context base. It also provides a means of agreeing with others about shared knowledge, coupled with consistency verification whenever the personal context base is accessed or changed. Consistent interaction with shared information leads to understanding of one's position by others. Our mantra defines understanding to be:

Definition: Common understanding results from the availability and consistent use of shared knowledge from many viewpoints.

Humans want computers and computer systems to react to events or their inputs like they would have reacted in the same situation. Humans want to have confidence in the system to deliver what they think they asked for or what is required to match the situation. Alas, "the situation" is often a context that is too complex for computer programmers to understand in advance of the fielded situation and its myriad possibilities. Therefore, each signal must be placed in a limited context that is specific to the individual and the information available to the computer. In the Intelligent Exchange, humans train the computer what is important for sequences of situations, then the computer could respond correctly, within the bounds of its experience—that is, understand the user's "signals" and act accordingly. Standard knowledge based systems collect static knowledge of a few experts. They often fall short of providing the mastery from each individual in the context of their mission operations. Important tacit information may fail to be collected because the series of events that the individual faces may never have been experienced by the expert, only by the using professionals.

4.3.4 Personal Viewpoint & Mastery Control

Our thésis is that people make systems work, and that personal control would facilitate this control. Every one of the involved humans is different. They have different views of reality and operate in a different legacy environment. This means we must take the detail burden of the computer's away from the human's field of view. We must do it accurately by matching an agreed upon and limited "common" ontology or view of reality. This model of reality hides non-linearity and complex interactions from the user. The desire of users is:

"The machine should know me...and where I am...and what the situation is"

This is necessary for security as well as for knowing trains of thought and context. The system might detect your mastery of the subjects as a telegraph operator could recognize the hands of each of the others on the wire. If you interact inconsistently with your prior viewpoint or mastery, the Intelligent Exchange would question your right to make changes or operate the entry point.

A mechanism for the Intelligent Exchange to guide its own process is necessary. The human helps connect data events to form observations. Then, by example, the response to the event is captured. This personal creation and storage of mission specific knowledge for each individual is the capability that leads the Intelligent Exchange to provide a repository and perception and reaction mechanism. This control is the capability to combine and name objects and events,

group them into larger scale chunks and deal with them as a symbol. In order to create operational sequences based on event observation, the Intelligent Exchange requires a means to define and store an automatic reaction to known events. This allows the Intelligent Exchange to bypass the user and act accordingly. Thus, the user can easily and safely ignore masses of common data and concentrate on dealing with the exceptional information and combinations of observations. A user might have several favorite viewpoints, each for a different situation.

4.4 Support Mechanism Layer

Supporting mechanisms are necessary for scaling and feasibility. Users cannot be expected to engineer robustness measures for safety, security, availability and reliability. The integrity of the system also depends upon the models used to project proposed activity. Control of the movement of needed system state and mission situation information to the user's entry point is required. A distributed application is needed to perform these functions. As shown in Figure 4-2—Entry Point Application of Intelligent Exchange Capabilities, the support mechanism layer consists of Robustness Services, Situation Communication, Extensible Decision Surface and Knowledge Reference Base.

4.4.1 Robustness Services

The robustness component of the Intelligent Exchange prevents the user from overloading system resources and from effecting the system's robustness by requiring reconfiguration of the personal decision system to match resource capacity. Intelligent Exchange would provide robustness and time response, while maintaining confidence of the users in overall system effectiveness. Intelligent Exchange also gives users the capability to choose robustness measures consistent with their immediate needs, possibly getting information faster but at the higher risk of faults or compromise. Thus, Intelligent Exchange would give a choice of getting a small amount of critical information when it is needed, instead of massive amounts of information not needed to respond to immediate mission demands. The warfighter would be guided to spread their accesses over a common time period in order to increase their individual information content without interference.

The feasibility of using harnesses to control a distributed operation is known. The effectiveness has been demonstrated. Commercially available technology allows the assurance of communications, resource allocation and process allocation—eg, ISIS. Some time control software is available—eg, ObjectTime. Access to objects could be via CORBA or OLE. However, the synthesis solution depends upon prediction with respect to authority constraints, resource consumption and time delays. This is provided by the Intelligent Exchange's confidence constraint and model component. In addition, it depends upon creating high-confidence methods for safety, security and availability for this environment.

4.4.2 Situation Communication

Providing the necessary information content at every command level, site locale, battle situation and command function is daunting. Since no specific information is available the system builder must deliver an excess of information to make sure the individual's needs are met. Providing too much information overloads both system and user. Providing too little of

the right information at the right time might lead to serious planning and execution mistakes. There is only one person that can define their needs accurately and precisely – the warfighters themselves. Intelligent Exchange is a method to relieve the system and software developer from this daunting task. The Intelligent Exchange creates a shift from developer-centric to user-centric systems. The change frees system designers from resource placement challenges by allowing them to be evolved to meet the warfighter's needs.

The response of the system to the user's demand is to verify that the system resources are within the limit set by system capacity and operational confidence constraints. Some users may be at places in the hierarchy that collect and distribute information. Sensor inputs, situation reports, salute reports, etc., would be fused if needed locally or transmitted higher up in the command chain. The same flexibility control would be afforded the user, except that information critical to the system as a whole could not be de-selected.

4.4.3 Extensible Decision Surface & Access

The Intelligent Exchange must have a highly flexible and robust adaptive decision technique – to fit the needs of player-to-player viewpoint understanding and for effective situation dissemination. At first glance, neural networks(NN) seem to be a good choice. For example, an NN could be used to decide when and what to do when events occur that change state or mission situation. However, once trained for a defined scenario or dimension, NNs are difficult constructs when the scenario or scope changes. After long term use, they resist decision surface refinement and expansion if new outcomes, observations or numbers of nodes are required. For example, a neural network needs to be able to grow beyond its original designer's concepts and initial exemplar and dimension set [Solinsky].

Our belief that "common understanding results from the availability and consistent use of shared information across all viewpoints" leads to a requirement. This is that the user must be able to constantly update the Intelligent Exchange with new and diverse sets of data, information, reactions and access controls. The Intelligent Exchange provides a mechanism for building both personal and multiple shared knowledge bases. Using the knowledge is accomplished by exception. The Intelligent Exchange deals with observation objects by evaluating an object with respect to its mastery base. If it is "familiar" it makes an automatic response (that is included as a part of the remembered familiar object). If "unfamiliar," it presents it to the user set for action. The user may discard the unknown object, fix it by adding viewpoint components or link it to other observations. It is made a part of the knowledge mastery base by naming, noting a reaction and storing it.

4.4.4 Mastery & Knowledge Reference Base

The complex object may be a set of multimedia objects that are coupled together to conform to a given viewpoint. Each viewpoint is represented in information space by a name, a parametric characterization, content based keys, and references to the objects from which it is composed by the Intelligent Exchange. The language is used to act upon the complex object. It can do the following:

- create new viewpoints

- reinforce (remind) the long term memory
- instantiate new (formally unfamiliar) objects into long term memory
- fix unrecognized objects
- discard some as unimportant flotsam and jetsam
- create an observation to be tested

The user may also browse through the long term memory by creating a series of observations to be recognized or not on the decision surface. The decision surface is adaptive, like a neural network, and improves its search and correlation based on learning.

By shifting to another stakeholder's shared viewpoint their concepts about the model can be checked. During model generation capable stakeholders would modify the model presented from their personal viewpoints and verify those from other viewpoints. This generates the shared context reference. The Intelligent Exchange lets the observer focus on a personal model suited to the context and situation through viewpoint control. The Intelligent Exchange can be configured as a tool that builds, from the initial descriptions, a complex object diagram that represents a common model. Each stakeholder has their own viewpoint of this "model." They can view the object from their personal viewpoint that compresses detail beyond the user's conceptual range. By making observations on the context base the model can be tested for conformance of their viewpoint to the shared context base.

5. Conclusions about the Intelligent Exchange

5.1 Observations

The needs of the 21st Century Metasystem that emerge either involve or rely upon the human-system-human interface in one form or another. Solving the interaction issues of systems to users, operators, maintainers, builders, commanders, and any other stakeholder is the critical element of success factors in creating large-scale systems. A leverage technology must address this critical element if it is to meet the long range vision.

We observe that important parts of each success factor either interface or change the system's human involvement, organizations, institutions or legacies. This leads to a fundamental observation about building large-scale systems:

> *Humans are a necessary instrument in making complex and changing things work. To make his contribution effective, each Warrior needs the capability to control a personal information space that empowers him to express their knowledge and mastery within the system.*

The abstract creations of humans (eg, institution, organization, doctrine, legacy systems, communications with others, incorporation of new technology into the infrastructure, and so forth) cause complexity. They are workable only if accessible and understandable by other humans at many levels of operation. Each of these has mechanical interactions as well as human interactions. The Intelligent Exchange should relieve the human of the mechanical aspect and let the human guide the non-mechanical.

The result is an enabling set of ideas for "Incorporating Human Intelligence & Mastery Into Systems" and a technology solution called the Intelligent Exchange. By "intelligence" we do not mean that the system is intelligent and performs like a human might in general, but that it has:

- Automatic features for a limited (but complex) context which adapts to meet the Warrior's and System's effectiveness needs
- Significant involvement and control by non-programmer humans who are professionals in their application domain

The goal is to provide a framework for flexible personal control. This control enables the user to add his own capabilities and knowledge to the system, allowing him to make the system work in numerous situations that could never be anticipated by the computer programmer. The intelligent interface technology provides the feedback necessary to verify the impact, safety and security of changes to doctrine and organization. These changes are highly oriented around human perception and knowledge. Key to this is to include the capability to collect measurements that allow the evaluation of how the individual capabilities sum up to a complete system operation. The Intelligent Exchange requires projective consequence models

with the capability to predict global impacts due to perturbations by individual actions and decisions.

5.2 Impact of the Intelligent Exchange

The Intelligent Exchange makes a direct impact on command infrastructure and interoperability issues. The introduction of new forms of data collection and display that cannot be easily related to corporate ingrained operating procedures causes disruption and loss of effectiveness. New systems may provide too much data without the means for interpreting it in the context of the standard situation. The goal is to provide each system participant the capability to adapt his interface to meet his own level of experience and training. For the warrior this means the capability to compose an information gathering and decision system from available components. Multiple warrior roles are necessary to meet needs at all levels of command. These functional participants should have interface tools that allow them to reconfigure data to forms most familiar to their skills and heritage. For example, getting a screen copy that they can measure and make calculations consistent with other ruler, paper and pencil technology they must use. Thus, getting data into the hands of the participants is made the responsibility of the users themselves. They are empowered to configure it in a form they readily understand.

Results reported on the Workshop on Engineering Systems in the 21st Century [Crisp] agree with much of this report's conclusions. However, the workshop ignored one solution to the problem of increasing complexity—that a technical solution must be found to directly limit complexity. The workshop focus groups seemed to accept any complexity exacerbating factor as a given and then try to build around it. This report has a different viewpoint. This is that, unless complexity is kept constant at today's levels, it will become impossible to handle with any system engineering method. Solutions must be found in approaching the entire organizational chain of authority. This means that the human elements or organization and interaction must be understood and incorporated. Technology alone cannot solve complexity issues that are created by humans. The context is too broad and changeable. Therefore there can no longer be the expectation that large scale systems can be built without the complexity reducing involvement of all the stakeholders. The requiring stakeholders must be an active part of the system during development and deployment. Without such measures to restrict explosive growth, the system state and mission situation recognition and response controls become impossible to implement because size, scaling, and response times grow exponentially. The Intelligent Exchange is a means of overcoming this barrier.

5.3 How the Intelligent Exchange Enables the 21st Century Metasystem Success Factors.

We found, first, that the success factors have a number of supporting elements and technologies and, second, that critical parts of each require the involvement of humans and human created organizations and systems. Considering that a general theme we can focus on this as a broad for each of the success factors.

The success factor, "Closing the Gap Between Demonstrations and Fielded Systems," would be enabled by giving users the control and flexibility to define their own system viewpoint and

operating environment within the metasystem. This lets the user put the information in the form he is used to seeing it. By creating this flexible user entry point the metasystem can be stressed during "continuous virtual" warfare training and simulation while the users improve their personal control. Since entry points are individually tested the system builder can concentrate on providing scalable resources. This makes development and demonstrations scalable and fieldable for military use because these interfaces can apply to autonomous agents that are trained by a human to perform system interface scaling.

The success factor, "Reengineering Warfare" would be enabled by projecting a user's proposed action to determine if it is within doctrine, order of battle, command, common plans and other bounds. By providing the flexibility advantage with the confidence constraint it will be easier to attain acceptance of change in the military structure as required to take advantage of advanced technology. In addition, the personal flexibility allows users themselves to incorporate the changes in structure and their viewpoints necessary for fitting new technology into the military infrastructure and overcoming legacy, interoperability and training obstacles.

The success factor, "Creating & Integrating the Metasystem," would be enabled by creating a personal control entry point to the metasystem. This would extend into the metasystem to obtain needed information, situation information and the latest models for battle commands. The risks in "building the metasystem" are not from the inability to apply massive communication and computational brute force. These risks are due to the doubt that human activities of building, using and incorporating the metasystem can actually be accomplished. Complexity would be reduced by concentrating on testing and verifying each individual entry point the metasystem is made less complex and can be constrained to operate within the complex system. The second element that personal control by the user for metasystem operations is that the users are recognized as a necessary part of the system from its conception. Personal flexibility and control are guarantees of intense user involvement in large-scale systems, a missing factor in many large scale system projects.

The success factor, "Meaningful Communication & Common Understanding," would be enabled by providing a mechanism for verifying consistent use of information provided by a user. Whether being used for their own flexible use or for sharing the information, a conceptual consistency verification would contribute to common understanding in human-to-system-to-human communication. Finally, personal control would mean that the user could create a set of personal viewpoint, consistent with the situation. This would mean that a user would transform overwhelming data masses pouring into the metasystem into useful information for his own reaction or reflection.

There is a major theme related to a solution to each of the success factors: each of them critically depends upon the interaction of humans and systems. Thus a leverage technology must address this aspect of the four major success factors. We advocate that human involvement is necessary to achieve each of the success factors and to make the metasystem work effectively. Thus, the Intelligent Exchange, provides the personal flexibility and control necessary for achieving critical parts of the 21st Century Metasystem vision success factors.

5.4 Benefits and Summary

The Intelligent Exchange establishes the means to flexibly choose and timely receive the information required to perform their mission. The Intelligent Exchange's warfighter-centric approach lets each individual choose the information that suits their particular situation, level of command, and role. An Intelligent Exchange would provide versions suited for roles in mission planning, including battle, logistics, personnel, intelligence, personnel, aircraft, etc. Each role player will be able to select information requirements that are available from various network sources and suitable for different situations. Knowledge bases and associates would be incorporated in the layer below the Intelligent Exchange. In the Intelligent Exchange operational scheme, the individual warfighter builds a personal information system from a library of information system components, connecting outputs to inputs and setting conditions for execution of the components. The user may also set the required robustness on a component by component basis. To prevent excessive demands, Intelligent Exchange automatically restricts choices to correspond with command confidence constraints and resource capacities.

The Intelligent Exchange puts a high level of information system flexibility in the warrior's hands. It incorporates "dial-a-mission" functional information system operation, coupled with system integrity and robustness operations for safety, security, survivability and reliability. The warrior user can choose features that match his mission's information modules and the battlefield situation. The Intelligent Exchange allows highly flexible configuration of information gathering, action planning, modeling and decision making components. However, warrior choices are constrained to ensure fair resource use, robustness, and timely response. Intelligent tools and interactive models are used to accomplish this. The Intelligent Exchange preserves the general control and authority of the command structure, giving commanders the ability to coordinate wide-area thrusts. Thus, the highly flexible, personally directed, information-gathering system is well suited to individual warriors, the command structure, and the system builder and maintainer.

5.5 Research Recommendations

Each of the elements of the Intelligent Exchange contains research areas that are already recognized. The Intelligent Exchange is a concentration of several technologies toward flexibility and personal control. Present research directions can be monitored to ensure that they are consistent with the direction and needs of the Intelligent Exchange and its goal of personal control.

The descriptions of the Intelligent Exchange elements define research requirements. The following are a recap:

- The Personal Control User Interface requires that research be conducted into how the user views, directs and interacts with the Interaction Layer and the knowledge, objects, functions and data contained in the metasystem.
- The Safe Synthesis and Personal Viewpoint & Mastery elements of the interaction layer depend upon a presentation that can be manipulated to match the understanding of the

user. Safe Synthesis requires that component fusion methods be extended to allow the user to harness components with safety from deadlock or other problematic situations.

- Confidence Constraints and Models requires that projections be made from the scenario created by the user's definition of reaction to events. Since the events may be a complex interactive set of numbers of detections and events within the metasystem, this projection may require automatic verification of completeness.
- The Consistent Personal & Shared Interaction element provides a meaningful interaction among them. Research investigations on how to create both a personal veneer and several shared knowledge spaces above a standard knowledge base are required. The Consistent Interaction element also depends upon the ability of the numerous users to understand, in their own terms, consistently the same set of knowledge. This may require that computer scientists take a step back from advanced exotic methods of data viewing. Users must be given the power to recapture the look and feel of familiar views of information, even if these are archaic compared to virtual reality caves, etc. On the other hand, these reality methods may still be too primitive to accomplish the needed ability of the user to cast information personally.
- The Personal Viewpoint & Mastery Control element requires research on the representation and presentation so that each user be able to change his focal point in his personal mastery reference and view the information accordingly. The representation should allow the user to understand the content and to change the representation to different forms.
- The Robustness Services depends upon the development of High-confidence methods that can be provided as services by the system technology.
- The Situation Communication element requires a common shared view of the activities, plans and goals within the battlespace. The Situation Communication element requires research on recognizing which information is needed by others at each entry point and integrating this into a circulation pool that keeps the requesting entry point adequately informed.
- The Extensible Decision Surface requires research in decision making methods that do not become rigid as they are trained. They must also incorporate very different information across very different ranges of data and retain their effectiveness.
- Representation research that leads to an effective Mastery & Knowledge Reference Base is required. Such a formulation would capture both the advanced capabilities of advanced KBSs as well as the object formalizations of C++ and Object Data Base Management systems. (The user must be able to access and incorporate information and its relationships in many forms.)

The general programming models and global access methods required as the foundations also require significant long range research. However, present methods for distributed systems are likely to be far enough in the future that a limited Intelligent Exchange could be demonstrated. A related research area is in exploring the required support necessary in operating systems. The present directions in commercial operating systems and tools may make it impossible to

create the necessary intimate control. This control is needed to be put into the hands of the user to accomplish an effective level of personal control.

The first step research recommendation is that a preliminary design and effectiveness metrics be defined with respect to each of the Intelligent Exchange elements. A form of the Intelligent Exchange could be defined using existing commercial technology—eg, an Internet based Intelligent Exchange. The metrics should be used to evaluate the weakness or strength of commercial support. This would define the information that flows between elements in more detail. An initial set of metrics and representation of the metasystem and its contents. The metrics should establish the means for display of simple views of complex operations. For example, visualization of object relational spaces used to represent knowledge could be coupled with the ability to recast it from a different viewpoint. In other words, change the center of focus from one part of the representation to another. Internet-enabled, knowledge-based browsers may be a good starting point. The next step is the capability of the user to interact with both the knowledge base and capabilities of the metasystem to express new relationships and actions.

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Appendix A:

General Technology Needs In Warrior-Centric Systems

APPENDIX A: GENERAL TECHNOLOGY NEEDS IN WARRIOR CENTRIC SYSTEMS

Appendix A:

General Technology Needs In Warrior-Centric Systems

1. Warrior-Centric Systems Research

This Appendix discusses the general foundation that is necessary to make the Intelligent Exchange easier to build and operate. Its theme is that building the metasystem requires applying the Intelligent Exchange to the user's and operator's roles to let them make the system work. These are general technology needs for creating Warrior Centric Systems. Research in these technologies is needed to build the metasystem irrespective of the acceptance or rejection of the leverage technology "Incorporation of Human Intelligence & Mastery," and its realization "the Intelligent Exchange."

1.1 Stakeholder Confidence

Confidence in the systems-of-systems will derive from how well the system keeps to the user's own internal conceptual model. Yet each user, even an automaton, has a private model. The participants also may come from widely varying areas and levels of expertise. Therefore, a common understanding among different viewpoints of the parties, without face-to-face interaction, is critical to successful collaboration. This is the essence of the Intelligent Exchange—ie, a capability to form an accurate and meaningful channel between different entry points and roles in the system. Therefore, after ensuring that each role player gets the information they need, the system must map its information into each player's conceptual model. Since players may have varying areas and levels of expertise, and are using the information for different decision making purposes, the system becomes increasingly complex.

1.2 Complexity Solutions

A solution for complexity is an adaptive interface—the Intelligent Exchange. Its role is to help the users and operators intelligently glue together both legacies and existing systems into a systems-of-systems—ie, letting humans make the metasystem work. A second goal is to create a means of decimating the complexity of large scale systems. In this role, it is used to provide a mean of building the operational robustness services. Meeting these goals would guarantee safety, security, availability and reliability services for mission functions and for the interchange of information between entry points and server points. Its basis for complexity reduction is twofold:

- A testable, flexible and safely operating entry point for each user that allows distributed system resources to be identified and applied by user harnesses to control events—ie, a Global Event Access, Control, Search and Identification Mechanism
- A commodity-oriented interaction mechanism that provides a synchronizing programming model that yields predictable time response for functions and robustness operations—ie, a General Synchronization Model

2. Global Event Access, Control, Search & Identification

Our overarching goal is to define a decision technique and framework that lets us build complex, intelligent, interactive systems. In order to be workable and scalable it must be inherently distributed—ie, no central mechanism is allowed. It must be independent of the workstation development environment. It must scale naturally as number of players and locations increase. It must have guidelines and metrics to help engineers set boundaries, control feedback, and test each viewpoint individually. In addition, it must be well suited to adaptive training through frequent player or automaton operation in simulated combat environments.

2.1 Domain Interoperability—Serving Complex Patterns

DARPA expects object-based software to allow information movement between domains [Urban]. (This infers a solution to a number of interoperability issues.) DARPA also expects to understand data storage and system architectures well enough to extract and synthesize usable knowledge from large volumes of data. Another viewpoint is that the "Web" approach, when combined with active object methods, will provide a solution to large scale system building. The belief is that, out of necessity, the Web/Internet model will bring about software engineering changes. These will create an interacting component industry [Mills]. The related success factors for this change are: a resolution to security, censor-free interchange, an open system and adequate system support. The primary factor that may inhibit the Web/Internet from this goal is the capture of Web/Internet standards by a few enterprises. This model has a necessity for continued openness.

Another similar approach is the entry point model used in the Intelligent Exchange. In this model, complex systems are built by assembling the technical resources for a generic set of operations. Then each entry point uses the system's resources to accomplish its mission. Each entry point is fully tested and understood but no attempt is made to understand the complex resource providing metasystem at detailed level. The operator builds robustness services by harnessing components using the same tool. The system resource provider allocates resources to meet the time response goals of the operator and user operations. This commodity-oriented model depends upon making the interaction between the entry point and metasystem independent of other entry points. In the commodity-oriented model the metasystem knows nothing about the applications and operates much as a large telephone company provides communications and other services.

Some difficulties do arise in the entry point approach that are resolved by the Intelligent Exchange. It forces each entry point to be well behaved by applying a confidence control model that limits operational impact on system resources. This is an attempt to overcome the non-linearity of the system by staying well outside any region of instability. We have assumed that this system model is propagated among the entry points to provide the information needed to build the models. We do not anticipate that these models are exactly the same at each entry point. We assume that any needed information is sent there. The operational dynamics require that a sufficient factor-of-safety be included to overcome model differences. The propagation time across the network of the model must be below some time period that does not allow instabilities to occur.

2.2 Providing Cognitive Bandwidth

In the face of myriad real world threats and time critical environments the cognitive bandwidth is very important. (Cognitive bandwidth is the capability of the human to concentrate and recognize a situation based on observed relationships.) DARPA hopes to extend the number of attention objects by using more senses—eg, adding a skin vibration to locate friendly or enemy forces. This sense may be added to the standard number of visual events within the cognitive bandwidth [Urban]. A critical factor is that system interfaces must provide event and information fusion that reduces the sensory overload.

2.2.1 Situation Understanding

Research is ongoing in organizing paradigms for virtual interaction to resolve understanding differences. Caves and virtual reality tools were anticipated to give better collaboration. They are believed to significantly improve the communication of the context about one's working space. However, many have little confidence in collaboration methods due to the difficulty in communication of understanding using computers.

Access security on battle information systems will be enhanced because the system can identify the user and respond to his or her methods and patterns of operation. Many elements of the user's presence would be detected: image, hand, finger and eye prints, voice and typing patterns, consistency of interaction with special knowledge.

We stress understanding of a "situation" that cannot be totally, completely or directly observed. Observations, upon which collaborative decision making is based, are automatically gathered and interpreted by myriad system participants. The "situation" typically has many different components and locations associated with different role players. This is expressed for AI by Lugar and Stubblefield: "*Search spaces for interesting problems tend to grow exponentially...*" [Lugar]. Because of large, hidden state, systems with interactive objects are inherently less testable than conventional processes[Binder]. A broadcast of the complete and complex state would likely be beyond practicality because the overall situation, state diagram and search space sizes grow exponentially as complexity increases.

2.2.2 Object Control Understanding

The Warrior must have some understanding of the object to be harnessed into an application before he can find it and make use of it. A technology for increasing the capability for better understanding of specifications by stakeholders is necessary [Solinsky]. The external specification in object-based technology is not always adequate to truly explain the meaning of the internal operations. Programmers often read the internal method implementation code to understand what the object's external specification actually means. This violates the information hiding principle of object-oriented theory. Since the external description of an object's method may depend upon an English text description, it cannot express the computational meaning of the object as exactly as the code itself. Only in the cases when mathematical algorithms (or formal proofs) are available can the programmer easily understand the meaning of a method or the object's organization of data. Significant aid of this

type is also necessary to overcome the difficulties in relating complex parameter sets to operating systems and communication networks to system models.[1]

2.3 *Intelligent Authority & Resource Constraints*

From the user's point of view, information components can be selected up to a limit. This limit must be automatically imposed by constraints-based on to robustness level, system capacity and time responses. Constraint-based interfaces for data-base access often perform similar functions, albeit they do so in a much simpler context [Kobryn]. For capability fusion, resources are also to be allocated automatically—up to the limits of linear system capability. A cost function constraint would allow limits on information function choices according to the functional needs defined by the user, not by someone that understands information systems, but does not understand the mission or situation. The component providers—ie, servers—are likewise understood and modeled according to the demands that they place on the system's computation and communications capacity. (Note: The Confidence, Constraints & Models Function in the IE performs elements of this general need.)

One response of the system to the user's demand is to verify that the resources are within the limit set by system capacity and operational constraints. Some users may be at levels in the hierarchy that collect and distribute information. Sensor inputs, situation reports, and salute[2] reports might be fused there if needed locally or if transmitted higher up the command chain. The same flexibility control would be afforded the warrior, except that information critical to the system as a whole could not be de-selected.

The technology required includes a system cost model that represents the cost of the user's demands on the system. A global model is required and is distributed to each user site. Constraint-based, Artificial-Intelligence methods are appropriate for the optimization necessary as the warrior reaches the limit of allowable function. Note that an initial capability can be obtained through simple allocation, but that the needed capability is one that performs adjustment and tuning over time to optimize the system.

3. General Synchronization Models

The warrior's personal decision system should allow the necessary harnesses to be built by the professional warrior. He or she is not expected to be a programmer and cannot be expected to deal with state machine design. Thus, an automated means is necessary to deal with the state issues of the user. This requires that the state machine grow less aggressively. This is accomplished by enforcing true encapsulation of both the application and a dataflow object-to-object synchronizing mechanism. Component objects would be encapsulated by the

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1 The capabilities of Consistent Personal & Shared Interaction and for Mastery & Knowledge Reference Base contribute to the interaction understanding between Warrior and object developer. We place the topic in this Appendix to avoid creating a metalevel of applying the Intelligent Exchange to itself—although its use in reusable components and objects may lead to important leverage.

2 Salute reports are confirmation messages that orders are received and understood.

environment so they do not have to be reentrant. With this improvement in object fundamentals, it is necessary only to express the entry point's partial order execution. This provides component control and reduces troublesome errors from false sharing or reentrancy. A general synchronization and control programming model is needed.

3.1 Coordination and Synchronization

A second capability necessary is distribution and management of the state information necessary to maintain control of the system. A shared synchronizing object model coupled with scripting languages may be adequate. Several commercial languages provide this capability—eg, Transcript, ActiveX and Java. This would allow the system builder to better allocate, partition and place these synchronizing execution strings within a warfighter's information delivery system. The actor and applet technology defined by Transcript and Java must be extended to incorporate a shared synchronizing object model. (Present ones only support monitors and locks, which fail to meet the commodity-oriented qualities necessary.) The synchronizing capability gives an effective time control and robustness harness mechanisms that is needed by the synthesis solution.

Note that there is no single function or entry point within the system-of-systems with a complete picture of the global situation or total overall state. Each function of function or operational robustness harnesses has a set of parameters that must be validated by events within the system before the function is active. Once validated, the function is executed under control of the local intelligent interface, which imposes its own set of trigger conditions, authority and capacity constraints. The situation notice is distributed and operates in concert with a communication link, capturing and passing situation and state information among each of the nodes it supports. Each entry point maintains its local view with supplemental information it needs from the situation notice service. These situation notice services are only quasi-integrated because they must scale to any size system.

3.2 Predictable Interaction Between Entry Point and Metasystem

Application scaling of function or robustness, with constant time response, is a difficult design task. However, this is necessary for successful evolution of large scale systems. Application scaling means that, if an application requires a shorter time response, then a more powerful workstation, a multiprocessor or parallel machine clusters can be inserted with little or no software change. As the application is modified over time new hardware insertion could occur several times in the system lifetime. To accomplish this, the Intelligent Exchange research must create or find a suitable programming model. Applying this programming model to component fusion methods is the method proposed to reach time response requirements of the mission.

A "commodity-oriented" computational model is necessary to separate today's hardware and operating software from tomorrow's function and operational robustness. This programming model must allow prediction of time response based on simple parameters of the application—eg, average size, grain, concurrency and complexity. These parameters would be derived from the functional and robustness threads. The time prediction then depends upon the average

time to communicate and synchronize between tasks. Predictability of timing is necessary to ensure accurate resource loading modeling.

System performance models would include human interaction, entry point(client) processing, intervening communication and operational robustness services and exit point (server) loads. These models need to be incorporated into the software development process and displace the development workstation as the framework for testing components and operational robustness harnesses.

3.3 Component Fusion for Application and Robustness

Organizational and doctrinal change will stress communications systems in new ways. Particular solutions to military reorganization requirements are large scale communication systems that incorporate intelligent networks and adaptive switches. Fully fielded systems must go beyond simple point-to-point arrangements. The capability to marry multiple communication systems together (transparently) and demonstrate interoperability is necessary. Safety is another important factor. Simulation is necessary to demonstrate safety in large scale systems that have a requirement for high robustness and complex connections. Without confidence in communications the command hierarchy may remain relatively unchanged.

3.3.1 Component Synthesis

This need depends strongly upon the capability of stakeholders and system builders to create components, component harnesses and operational robustness harnesses. These must be capable of reducing the complexity of time response and operational robustness provisions by separating these considerations from the development of mission functions. The technology suggested by many is a component framework suitable for the application of selected operational robustness. In addition, these operational robustness harness services might be provided by the system builder or communication vendor as a utility. (Note: Specific requirements in this general technology need are captured in the Safe Synthesis and Robustness Services components of the Intelligent Exchange.)

Reusable software component technology is the subject of a number of other research projects. However, there must be an interface or encapsulation method provided to incorporate them into the Intelligent Exchange. Object-oriented technology is the basis for a number of reuse and encapsulation approaches. A graphical user interface for gluing is necessary. The resulting harness must also be object-oriented to maintain encapsulation. However, object-oriented methods have weaknesses that Intelligent Exchange research would correct to enable component fusion by users.

Application component fusion by the warrior requires additional component coordination harnesses for separation of application, robustness and time response programming. Composition synthesis, along with automatic partitioning and allocation, must remove human responsibility for dealing with system complexity. Also, warriors improve their selections to match their needs over a time period using virtual warfare training. Warriors would usually start with templates or macro programs and then refine them. Since the warrior has defined an application from existing components, the warrior must also test and verify his personal

decision support system to see the effects. Accidental creation of a large state space needs to be avoided.

This implementation must allow frequent communications and safe object-to-object synchronization that can harness components to achieve a higher level of robustness. Research in high confidence methods for distributed systems is necessary for establishing the methods to be used. Note that these may be quite different from conventional sequential formal methods for safety and security. Separation of the functional and robustness requirements into independent abstractions reduces complexity. Warriors cannot be required to understand the details of robustness algorithms for safety, security, availability and reliability. Therefore, the mission functional components should be capable of being defined independently of robustness implementation. After module design the separate mission function and robustness modules must be synthesized together into a consistent executable image. It may be impossible to create general methods for complete testing and formal proofs in object-based systems [Wegner].

3.3.2 Related Research on Robustness Threads

In a discussion of reengineering, Welsh shows robustness threads as a part of its overall diagram but the publication does not discuss their use. Their method is oriented around reengineering of existing systems and targets a known architecture instead of changing or recommending a new one. It primarily addresses the reengineering of existing systems [Welsh]. Time control mechanisms are necessary in robustness harnesses. A. Morzenti and P. SanPietro give a method for coherent and logical time control in distributed systems [Morzenti]. Also noted in the literature are fault tolerance and time control issues that allow one to embed time dependent properties and real time constraints. This is discussed by A. Perksich et al. Their approach is based on analysis of petri net (G-Net system). They avoid interference in software components caused by faulty hardware or software. They detect a fault and prevent it from generating additional errors. Their analysis is based on "fuzzy" time petri nets that, when violated, trigger recovery blocks. [Perksich]. D. Mostert and S. von Solms give a method that incorporates robustness mechanisms into the requirement statement. [Mostert].

3.4 Object State Space Limitations

Components and objects can lead to large state spaces that are poorly understood, making testing and verification difficult. The state of objects depends upon the sequence of prior messages, and if multiple messages are present that state is likely change during the execution of messages already in the method queue. Multiple inheritance exacerbates this issue since testing requires that the states of many objects might be involved, yet those are hidden from the user. Mechanisms that measure and allow the architect to reduce the state size and the complexity of object interaction are also needed [Binder].

3.4.1 Expression of Partial Order

When some of the elements of a list can be compared with other elements and yield logical results, while other elements cannot be compared to some other elements, the list is partially ordered. Interactive objects are an example because their state depends upon the sequence of

messages that came before. If the method called up by the message depends upon the state it may be necessary to look at many layers to determine what to do. The size of the state machine may grow exponentially [Hersh].

Also, it is difficult to create a compiler that can find the parallelism in complex sequential code. This is because the size of the state machine that the compiler must construct to parse the code grows exponentially. A compiler attempting to determine the execution graph of a program is looking at behavior—not structure like a normal compiler where opportunities for concurrent execution are controlled by the sequence of statements. Therefore, all the possible execution graphs must be considered. Each branch doubles the number of execution graphs. Since the number of branches is more or less a function of program size, the problem grows exponentially at the rate $k2^n$ [Hersh]. Builders of satellite computer systems maintain a strict management of design to preserve a finite state machine that can be resolved formally [Mott].

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